# The WELDING JOURNAL

MARCH 1952

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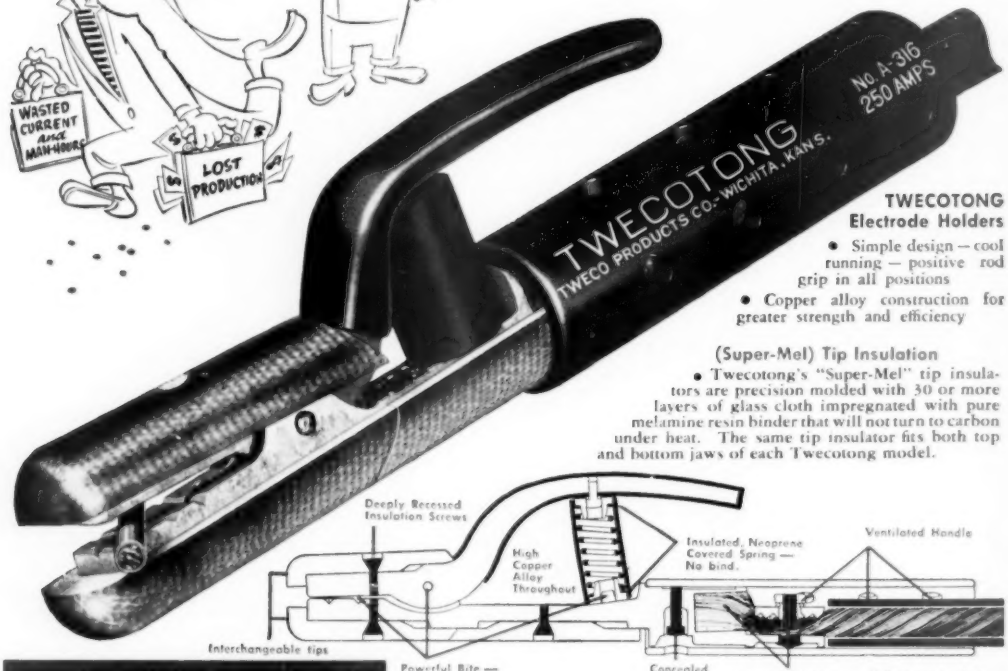


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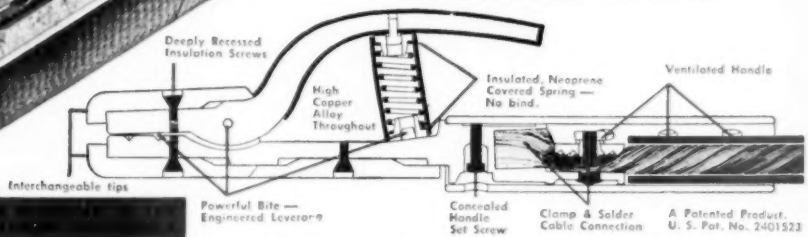
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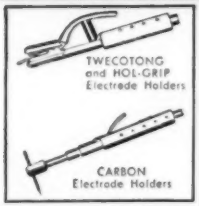


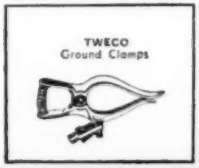


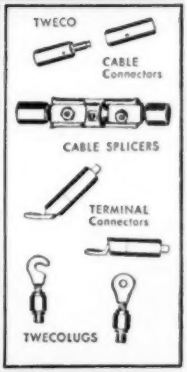


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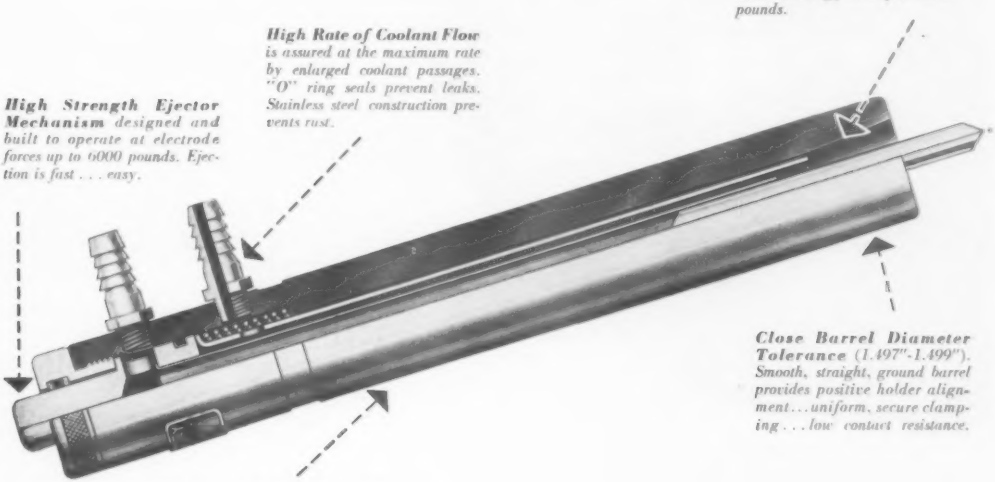

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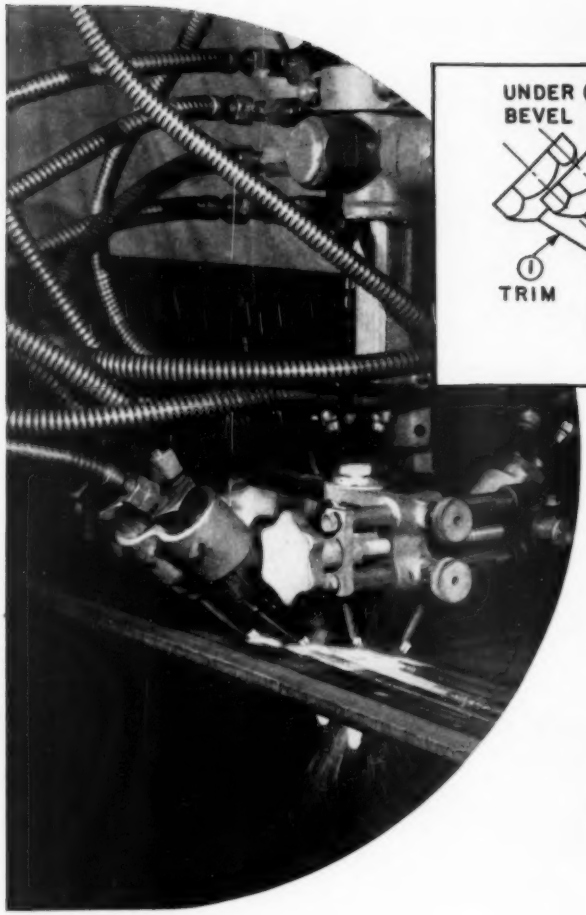

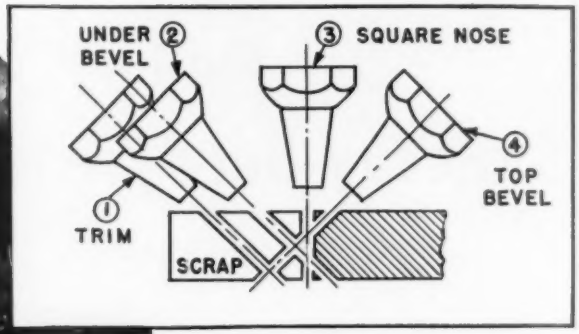


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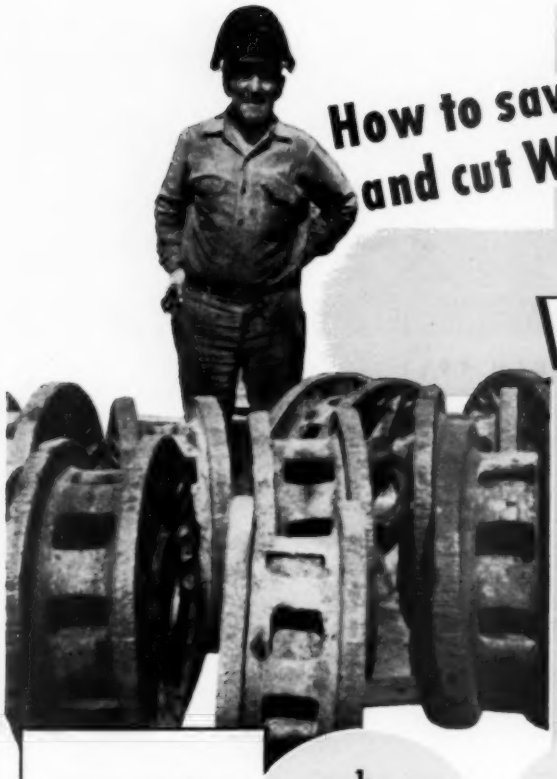

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volume 31 March 1952 number 3

# Surface Conditioning of Structural Steel

***Conditioning methods applied to structural shapes after rolling to eliminate injurious surface defects. Surface defects normally repaired by welding are tears, scabs and seams***

*by R. E. Somers and H. C. von Blohn*

## INTRODUCTION

THE surface conditioning of steel is defined as any operation to eliminate injurious surface defects. In this paper we will consider only those conditioning methods applied by Bethlehem to structural shapes after rolling. These include grinding, chipping and welding. After a brief discussion of the relative applications of each, we will devote our attention exclusively to surface conditioning by welding.

## OCCURRENCE AND NATURE OF SURFACE DEFECTS

In the manufacture of any rolled steel product, one of the primary considerations governing the control of processing operations is the necessity for minimizing the occurrence of surface defects. Nevertheless, a certain very small percentage of the product is subject to surface defects, and is separated from the remainder by careful inspection. The causes of these defects have been discussed extensively in the literature and will not be considered here. Surface defects normally repaired by welding are tears, scabs and seams.

## DEVELOPMENT OF SURFACE CONDITIONING METHODS

Before the use of welding was widely accepted, structural shapes containing surface imperfections were scrapped. Prior to 1936, the American Society for Testing Materials, "Standard Specifications for Steel for Bridges" and "Standard Specifications for Steel for Buildings" and other A.S.T.M. Specifications for structural steel, under the heading "Finish," stated only: "The finished material shall be free from injurious defects and shall have a workmanlike finish."

Beginning early in the thirties, as the steel mills expanded their use of welding, and as economic conditions tightened, experiments were undertaken to study the application of welding to the surface conditioning of structural steel. In 1935 a series of static and fatigue tests of structural steels was completed at Lehigh University, under the sponsorship of a committee of industry and government engineers. As a consequence of the favorable results of these tests, the 1936 edition of the A.S.T.M. specifications for structural steel permitted surface conditioning by welding within specific dimensional limits. The provisions for surface conditioning in the A.S.T.M. specifications for structural steel have remained in force, substantially unchanged, since the date of their promulgation in 1936. All of the producing mills in the U.S.A. took advantage of these provisions to weld surface defects within the established limits.

The latest edition of the A.S.T.M. specifications "General Requirements for Delivery of Rolled Steel . . . . for Structural Use" (A6-50T) provides for removal of shallow imperfections by grinding only. Deeper imperfections are removed by chipping and subsequent welding.

Grinding, or chipping and grinding, may be employed without subsequent welding on structural size shapes $^3/_8$ in. and over in thickness if the depression is $^1/_{16}$ in. or less in depth. For shapes less than $^3/_8$ in. thick, the maximum depth is $^1/_{32}$ in.

Sections $^3/_8$ in. and over in thickness, with imperfections more than $^1/_{16}$ in. deep may be chipped and welded provided the cross section is not reduced more than $1^1/_2\%$, and the surface chipped does not exceed $2\%$ of the total area. After the imperfection is completely removed, the maximum depth of depression

R. E. Somers and H. C. von Blohn are Engineers with the Research Department of the Bethlehem Steel Co., Bethlehem, Pa.

Paper was presented before the Thirty-Second Annual Meeting, A.W.S., Detroit, Mich., week of Oct. 15, 1951.

shall not exceed the following:

**Table 1—Maximum Depth of Depression for Given Thickness of Beam**

| *Thickness of material, in.* | *Maximum depth of depression, in.* |
|---|---|
| 3/8 to 1/2, exclusive | 3/32 |
| 1/2 to 1, exclusive | 1/8 |
| 1 to 1 1/4, exclusive | 3/16 |
| 1 1/4 to 2 1/4, exclusive | 1/4 |
| 2 1/4 and over | 3/8 |

The welding must be performed by qualified operators using suitable coated mild steel electrodes. The weld metal must project at least 1/16 in. above the rolled surface after welding, but is subsequently ground flush.

## MANUFACTURING PRACTICE

Typical mill practice, as it relates to surface conditioning, will be briefly outlined. Figure 1 shows a hot beam in the mill, where it is rolled oversize, so that when cooled to room temperature it will meet dimensional tolerances. The rolled beam passes to the hot saws, where it is cut to the proper length, again with an allowance for shrinkage to room temperature. After traveling over the hot bed, where it is air cooled, the beam goes to the gag press, where it is straightened. It is then inspected visually, on all four sides, for defects, true section and straightness.

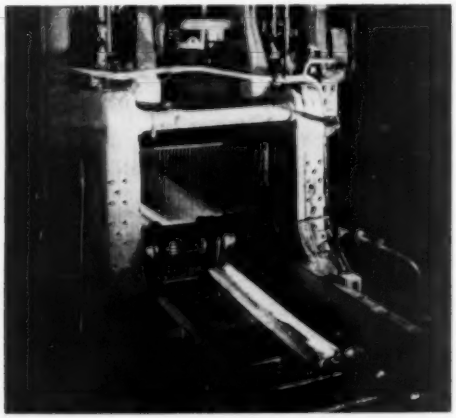

*Fig. 1 Structural shape in rolling mill*

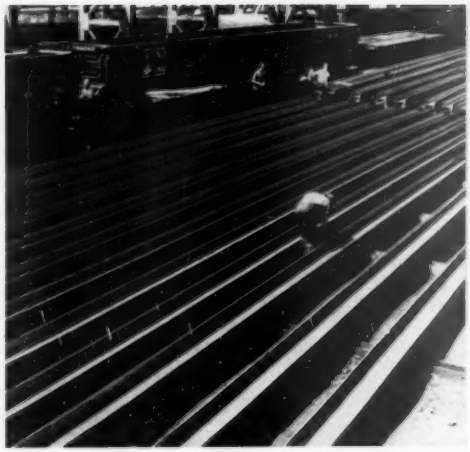

*Fig. 2 Inspection and repair skids*

## PRESENT SURFACE CONDITIONING PRACTICE

Beams carrying surface defects are routed to the inspection and repair skids, Fig. 2, where they are inspected on all sides. Surface imperfections are marked for grinding or chipping, depending upon estimated depth. Suitable gages are provided for measuring the depth to insure that the 1/16 in. maximum for grinding, without welding, is not exceeded.

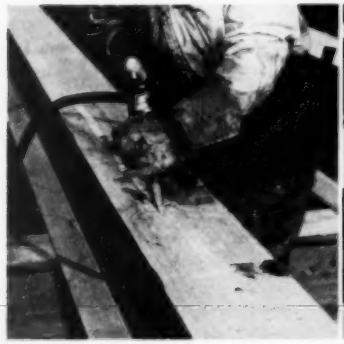

*Fig. 3 Chipper removing imperfection from beam flange*

*Fig. 4 Welder repairing imperfection in beam flange*

*Fig. 5 Grinding weld smooth after repairing imperfection in beam flange*

Other defects are chipped to sound metal and checked by gages for conformity with the maximum depth of depression specified. (See Table 1.) A chipper removing a seam in the flange of an 18-in. fifty-pound per foot beam is shown in Fig. 3.

The groove is then welded, using a low-hydrogen electrode conforming to American Society for Testing Materials—American Welding Society Specification A-233, Class E6016. The same beam shown in Fig. 3 is pictured after completion of welding, in Fig. 4. The "reinforcement" of the weld is then ground flush and smooth with the rolled surface, as illustrated in Fig. 5.

Upon completion of reconditioning, the beams are reinspected, and if suitable are stacked in the shipping yard with the remainder of the order to await loading. The finished product is pictured in Fig. 6.

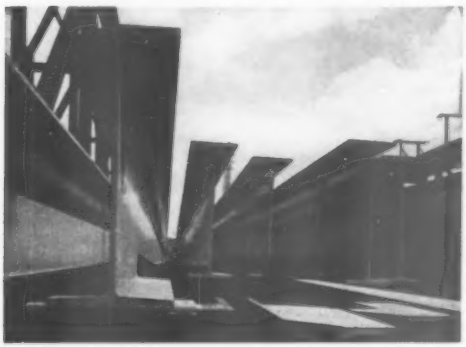

*Fig. 6 Beams awaiting shipment*

## CHANGE IN SPECIFICATION FOR CONDITIONING BY WELDING

From 1936 to 1949, A.S.T.M. specifications for structural steel, including "Structural Silicon Steel" (A-94), contained the provisions described above for surface conditioning. However, the 1949 edition of the A-94 "Specification for Structural Silicon Steel" prohibited the welding of surface defects. The A.S.T.M. Committee apparently felt that, as this steel can contain up to 0.40% maximum carbon (ladle), the possibility of underbead weld cracking existed, and excluded conditioning welding for this reason.

## INVESTIGATION OF UNDERBEAD CRACKING

As a result of this change in specification, an investigation of the factors leading to weld underbead cracking in the conditioning of structural steel was undertaken. The welding industry had already studied the role that hydrogen plays in underbead cracking, so it only remained to apply the information to our problem. But first a brief resume of certain information on weld underbead cracking is in order.

## OCCURRENCE AND CAUSES OF UNDERBEAD CRACKING

Cracking in the heat-affected zone of the base metal, near the fusion line of the weld, has frequently been a source of difficulty in the welding of higher carbon steels. A typical underbead crack is shown in Fig. 7, which shows a transverse section through an American Welding Society E6012 weld-bead deposited on 0.32% carbon structural silicon steel at a temperature of 32° F. This crack continues, intermittently, parallel to the bead. The occurrence of underbead cracks depends on the type of electrode used, the carbon and alloy content of the steel being welded, and the weld cooling rate. Underbead cracking is not usually encountered in steels containing less than about 0.30% carbon.

Zapffe and Sims[1] related defects in arc welds in steel to the presence of hydrogen therein. During World War II an N.D.R.C. project[2] investigated the presence of underbead cracks in welded plate, and related them to the quantity of hydrogen-producing material in the coating of the electrode.

The coatings commonly used on ordinary steel electrodes all contain some materials which produce hydrogen in the arc atmosphere. This hydrogen is readily soluble, in atomic form, in steel at temperatures above the critical, and is relatively insoluble at temperatures below this range. It is generally considered that

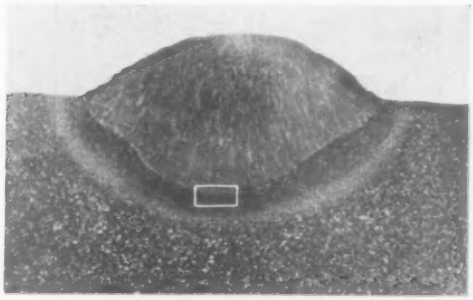

*Fig. 7a Transverse section of E6012 weld*

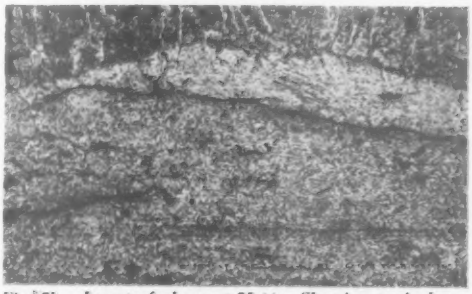

*Fig. 7b. Insert of above at 75 ×. Showing typical underbead cracks*

Table 2—Chemical Analysis and Mechanical Properties of Steels Tested

| Steel specification | Item | Analysis* C | Mn | P | S | Si | Ni | Cr | Mo | Cu | Ti | V | Mechanical Properties Yield point, psi. | Ultimate tensile, psi. | Elongation in 8 in., % | Reduction, % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Structural silicon | Specification | 0.40 max. | .. | 0.04 max. | 0.05 max. | 0.20 min. | .. | .. | .. | .. | .. | .. | 45,000 min. | 80,000/ 95,000 | 16 min. | 30 min. |
| | 12/16-in. plate | 0.42 | 0.67 | 0.014 | 0.023 | 0.28 | 0.02 | 0.07 | Nil | 0.05 | .. | .. | 45,850 | 94,730 | 21.7 | 39.4 |
| | 8- x 8- x 1-in. angle | 0.32 | 1.06 | 0.018 | 0.018 | 0.33 | 0.08 | 0.01 | 0.01 | 0.27 | .. | .. | 54,015 | 93,610 | 23.0 | 49.1 |
| Navy high-tensile steel | Specification | 0.18 max. | 1.30 max. | 0.04 max. | 0.05 max. | 0.15/ 0.35 | 0.25 max. | 0.15 max. | 0.05 max. | 0.35 max. | 0.005 min. | 0.02 min. | 45,000 min. | 84,000 max. | 20 min. | .. |
| | 8- x 8- x 1-in. angle | 0.16 | 1.20 | 0.024 | 0.022 | 0.28 | 0.21 | 0.06 | 0.02 | 0.16 | 0.009 | 0.06 | 55,540 | 82,215 | 26.8 | 64.9 |
| Mayari R | Specification | 0.12 max. | 0.50/ 1.00 | 0.06/ 0.12 | 0.05 max. | 0.10/ 0.50 | 0.25/ 0.75 | 0.40/ 1.00 | .. | 0.30/ 0.70 | .. | .. | 50,000 min. | 70,000 min. | 1,500,000 T. S. | .. |
| | 8- x 8- x 1½-in. angle | 0.11 | 0.83 | 0.074 | 0.025 | 0.31 | 0.60 | 0.49 | 0.01 | 0.69 | .. | .. | 51,495 | 73,385 | 27.6 | 65.9 |
| Steel for bridges and buildings (A-7) | Specification | .. | .. | 0.04 max. | 0.05 max. | .. | .. | .. | .. | .. | .. | .. | 33,000 min. | 60,000/ 72,000† | 21 min. | .. |
| | Web section B-14E at 342 lb. (1.55 in. thick) | 0.31 | 0.75 | 0.015 | 0.021 | 0.06 | 0.12 | 0.05 | 0.01 | 0.12 | .. | .. | 34,980 | 73,356 | 29.9 | 46.3 |

* Check analysis of material tested.
† 75,000 psi. max. for material over 1½ in. thick.

the hydrogen is rejected as the metal cools through sub-critical temperatures, escaping harmlessly at low-cooling rates, while at high-cooling rates it collects as molecular hydrogen in microscopic voids in the space lattice, and in so doing may exert sufficient force to cause rupture.

As a result of wartime research, coatings comparatively low in hydrogen-producing agents were developed for mild steel electrodes. A new classification for these electrodes was set up in the AMERICAN WELDING SOCIETY—A.S.T.M. A-233 Specification for "Mild Steel Arc Welding Electrodes." Classification EXX15 is intended for welding with d.c. reverse polarity, while EXX16 is intended for a.c. or d.c. Experience in welding a wide variety of medium and high-carbon steels with low-hydrogen electrodes has indicated that their use will eliminate underbead cracking under most conditions.

## RECENT TESTS

In a study of the problem of surface conditioning at Bethlehem, comparative tests of two electrodes were made: Class E6012, which is an all-purpose electrode previously used for surface conditioning structural steel; and the Class E6015 low-hydrogen electrode.

To determine the necessity for applying special welding techniques to various steels with different hardenabilities, four grades were tested:

1. Structural Silicon (A.S.T.M. A-94).
2. Navy High-Tensile Steel Specifications 48s5g and 46s1j (mild alloy steel containing vanadium and titanium).
3. Mayari R (low alloy, high strength).
4. Steel for Bridges and Buildings (A.S.T.M. A-7) (plain carbon)

The chemical analysis and mechanical properties of the steels tested are shown in Table 2. The sections tested were selected from available stock to obtain a minimum of 1 in. thickness and a chemistry on the high side of the specification.

## TEST METHODS

The two electrodes and four grades of steel were evaluated by (1) a laboratory weld cracking test, and (2) a welding test in the beam yard, simulating surface conditioning procedure, referred to hereinafter as the "yard test."

## LABORATORY TEST

This specimen, which has been used extensively at Battelle Memorial Institute for weldability work, is essentially a low heat-input weld bead, deposited on a plate under severe weld quench conditions. Figures 8 and 9 show complete details for making the test.

The weld bead is sectioned longitudinally and investigated for underbead cracks. The criterion is the pro-

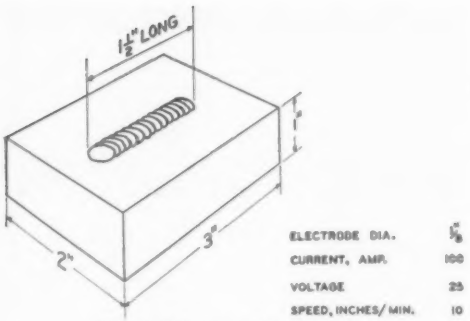


*Fig. 8 Laboratory test specimen*

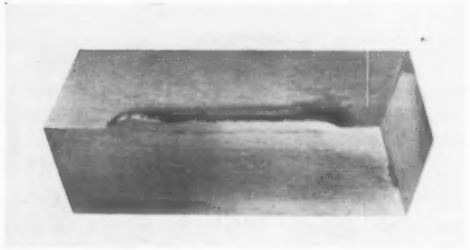

*Fig. 9 Laboratory test specimen magnetic particle tested*

portion of the length of the bead that contains cracks, the worst condition being cracking for the full length, in which the result is reported as 100% cracking. Following the practice established at Battelle, ten specimens of each condition were made and examined and the results averaged.

## YARD TEST

The yard test consisted of a welded repair of an actual rolled structural section. A simulated defect

**Table 3—Results of Underbead Cracking Tests**

| *Steel specification* | *Test* | *Electrode** | *Per cent underbead cracking* |
|---|---|---|---|
| Structural silicon (0.42 C) | Lab. | E6012 | 63 |
| | Lab. | E6015 | 0 |
| Structural silicon (0.32 C) | Lab. | E6012 | 45 |
| | Lab. | E6015 | 0 |
| | Yard | E6012 | 88 |
| | Yard | E6015 | 0 |
| Navy High Tensile | Lab. | E6012 | 0 |
| | Lab. | E6015 | 0 |
| | Yard | E6012 | 0 |
| | Yard | E6015 | 0 |
| Mayari R | Lab. | E6012 | 0 |
| | Lab. | E6015 | 0 |
| | Yard | E6012 | 0 |
| | Yard | E6015 | 0 |
| Steel for bridges and buildings | Lab. | E6012 | 17 |
| | Lab. | E6015 | 0 |
| | Yard | E6012 | 0 |
| | Yard | E6015 | 0 |

* E6012 is a conventional electrode. E6015 is a low-hydrogen electrode.

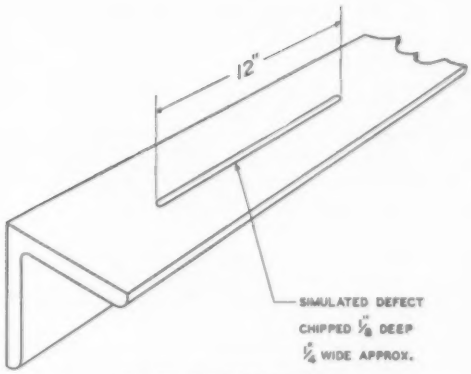


*Fig. 10 Yard test specimen*

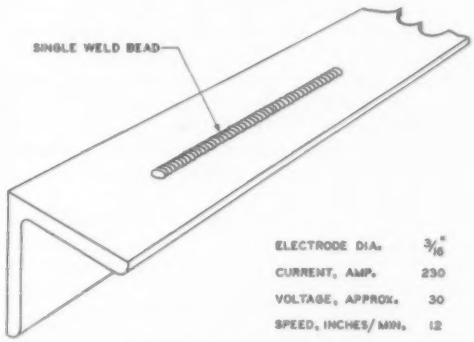


*Fig. 11 Yard test specimen*

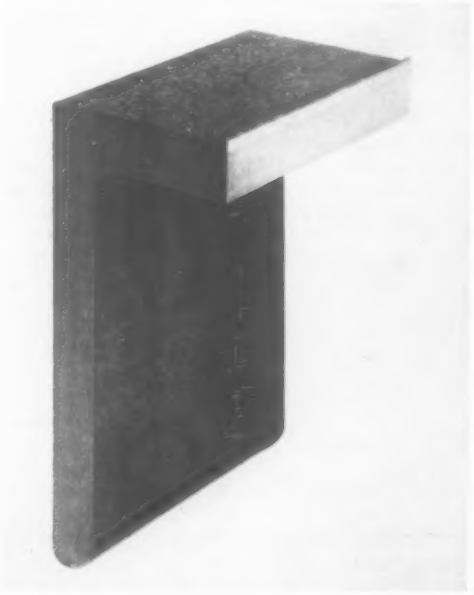

*Fig. 12 Yard test specimen section for inspection*

was made by chipping a groove approximately 1/4 in. wide and 1/8 in. deep, which was then repaired by depositing a single weld bead. The details are shown in Figs. 10, 11 and 12. The welds were deposited under fairly severe conditions, the ambient temperature being 32° F. or lower when the welding was performed. Six inches of this weld were sectioned and investigated for underbead cracks by methods similar to those used for the laboratory specimen.

## RESULTS

Results of the cracking tests are summarized in Table 3.

No underbead weld cracks were found in either the Navy High Tensile or the Mayari R in any of the tests. Cracking of the Laboratory specimens welded with conventional E6012 electrodes was noted in the structural silicon and A-7 steels. Underbead cracks were found in structural silicon yard specimens welded with E6012 electrodes. The fact that underbead cracks occurred in the laboratory test specimens of A-7 steel but did not occur in the yard test specimen, when welded with E6012 electrodes, indicates a borderline condition and is evidence that underbead cracking may occur in that steel.

There were no cracks in any of the steels welded with E6015 low-hydrogen electrodes. Figure 13 shows typical magnetic particle tests of a longitudinal section through the weld bead on two structural silicon yard specimens. The upper specimen was welded with an E6012 electrode and showed 95% cracking; while the lower specimen, welded under the same conditions but with a low-hydrogen E6015 electrode, exhibited no cracking whatever.

## CONCLUSIONS

1. In Structural Silicon Steel (A.S.T.M. A-94), conditioning welds made with E6012 electrodes under the conditions tested contained a high proportion of underbead cracks, while in A.S.T.M. A-7 steel for Bridges and Buildings a small amount of underbead cracking was noted.

2. The underbead cracking in A-94 and A-7 steels was eliminated by substituting low hydrogen electrodes for the conventional E6012.

3. Conditioning welds made on Mayari R and Navy High-Tensile steel with either E6012 or low-hydrogen electrodes contained no underbead cracks. This indicates that these two steels are not susceptible to underbead cracking under the conditions tested.

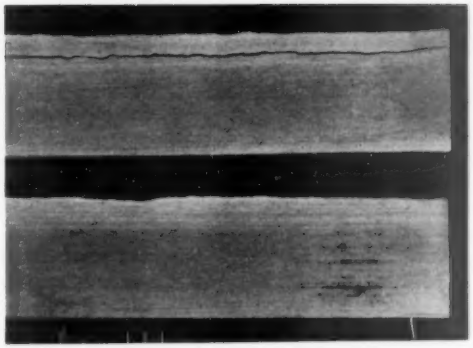

*Fig. 13 Longitudinal section of weld, structural silicon steel yard test*

(Top) E6012 electrode—95% cracking
(Bottom) E6015 electrode—no cracking

## SUMMARY OF SURFACE CONDITIONING PRACTICE

The surface conditioning practices we have described are applied, where necessary, and within the limits of the applicable specifications, to structural steels rolled by Bethlehem. Low-hydrogen electrodes are used on all grades of steel.

The current edition of the A.S.T.M. standard specification for Structural Silicon Steel (A-94-50) provides for welding in surface conditioning by agreement between the manufacturer and the customer. Two options are provided: (1) use of low-hydrogen electrodes, (2) preheat to 212° F. In view of the favorable results with low-hydrogen electrodes described above, and the time and expense involved in preheating large beams, we favor the first option. Bethlehem has been using the low-hydrogen electrodes for conditioning of structural silicon shapes with satisfactory results, since the 1950 specification permitting its use was published.

### References

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# Modern Developments in Metallizing

***Modern developments in metal spraying in sealing or impregnating the porous metal coatings to make them more resistant and impervious in corroding environments***

*by Sam Tour*

## INTRODUCTION

THE term "metallizing" is a general term applicable to the various processes used for applying a metallic surface by means of a spray or blast of molten or semimolten metallic particles. The blast or spray of molten or semimolten particles of metal may be obtained by the atomizing of previously molten metal, which in the molten condition is introduced into a blast nozzle to atomize it and project it as a spray. This is known as the Molten Metal Spray System. In general this system is limited to metals with reasonably low melting temperatures. The spray or blast of molten or semimolten particles may be obtained by introducing the metal in powder form into the heart of a blast burner to convert the powder particles to molten or semimolten condition and project them in the form of a stream. This is known as Powder Metal Spraying. The third method is to introduce the metal in wire form into the hot zone of a blast torch and as rapidly as the end of the wire melts to convert the molten material into a spray of finely divided molten metal particles. This method is known as the Wire Gun Method. Methods using an electric arc as the source of heat for melting wire and compressed air for atomizing the material so melted have been invented but have not reached success in commercial adaptation. The bulk of metallizing today is being done with the wire type of gun. This discussion on modern developments in metallizing will be limited to metallizing with the wire type of gun.

The first successful wire type of gun was developed some forty years ago. While the basic concepts of the original wire type of metallizing gun have been retained throughout these years, many improvements have been made in the gun itself. This paper will not attempt to list or describe the improvements made prior to some ten years ago. During the past ten years, wire-type spray guns have been improved to such a remarkable degree as to make the process of metallizing a fully practical "putting on tool" for continuous use in production work. The principal impovements will be described.

The complete process of metallizing requires more than just a metallizing gun. Proper gun auxiliary equipment is required. Improvements in auxiliary equipment during the past ten years have been instrumental in making the metallizing process the controllable process that it is today. Some of these improvements in auxiliary equipment will be described in this paper.

In addition to the gun itself and auxiliary equipment for operation and maintenance of the gun, there is still more involved in the present-day process of metallizing. Surfaces must be prepared to take the coating of sprayed metal. Methods of preparing surfaces and auxiliary equipment for use in such preparation of surfaces have been the subject of numerous improvements during the past decade. Some of these will be discussed in this paper.

Depending upon the particular wire used in combination with the method of surface preparation and the the actual spraying procedure, a large variety of types of coatings may be obtained. These metallized coatings may have and do have peculiar mechanical or physical properties as well as chemical properties. Studies in this field of spray metallurgy, during the past ten years, have developed a mass of important and highly useful technical data and specific information. These developments have made possible the continual expansion of the fields of application of metallizing and indicate ever-widening fields for the future. Some of these developments will be discussed. However, no attempt will be made to review all of the special applications of metallizing in specific fields.

The sprayed metal layer as deposited by a metallizing gun is inherently porous. The wide application of metallized coatings for corrosion protection has brought with it the development of numerous methods of sealing or impregnating the porous metallized coating. Top coats applied upon impregnated metal-

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lized layers make them even more resistant and impervious in corroding environments. Some of the modern developments along these lines will be discussed in this paper.

## IMPROVEMENTS IN WIRE GUNS AND GUN AUXILIARY EQUIPMENT

Prior to 1940 the improvements in wire guns had been to change them from crude pieces of equipment requiring continual maintenance by expert mechanics to precision built types of equipment which would be fairly dependable in production. However, the gun was still limited by its inability to spray large quantities of metal continuously by its susceptibility to variations in air pressure by variations in the rate of feed of the wire and by excessive wear in the wire feed mechanism. Other difficulties had to do with the tendency to backfire when using acetylene gas. Large amounts of compressed air were required per pound of metal sprayed.

Built into the wire gun itself is a wire feed mechanism which must draw the wire from a reel or a coil and feed it into the gun at a very constant rate. This rate of feed must not be affected by small kinks, bends or small surface variations in the wire. The development of such power feed units for incorporation in the modern wire metallizing gun represents one of the outstanding forward steps in the modern development in metallizing. The wire feed mechanism must be adjustable as to speed of feed to suit the particular metal wire being used. Wire feed units incorporated in modern guns are capable of giving constant feed of wire over speed ranges from as low as $1^1/_2$ ft. per minute to as high as 12 ft. per minute and maintaining this speed of feed constant in spite of air pressure fluctuations, kinky wire or unusual wire drag during operation. For higher speeds, gears are available for up to 30 ft. per minute feeds.

The operation of a wire gun creates a metallic dust. This dust is highly abrasive in nature. This abrasive dust must be kept away from bearings, gears and worm drives in the feed mechanism of the gun. Hand guns must be capable of operation in almost any position. Lubrication of the moving parts within the feed mechanism of a wire gun must be independent of the position in which the gun is held. One important feature incorporated in one of the modern guns on the market is the completely enclosed nature of the feed drive mechanism incorporating within it a forced lubrication system to give long life of bearings, worm drives and gears.

Recent improvements in wire nozzles in the end of the modern wire gun and in the method of mixing the oxygen and the fuel gas have made possible enormous increases in speed of spraying and at the same time have practically eliminated back firing. In one development a siphon jet system has been incorporated in the gun so that the oxygen stream issuing from an orifice actually sucks acetylene with it, making the gun much less subject to variations in the acetylene pressure and operable at much lower acetylene pressures than previous guns.

The modern wire gun is a scientifically engineered precision-built unit which will operate continuously hour in and hour out, day in and day out as all modern production tools should operate. The capacity of regular hand operated guns, using $^1/_8$-in. wire, and of a special gun for hand use for corrosion applications only, using $^3/_{16}$-in. diameter wire, are shown in Table 1. An all-purpose metallizing gun for use in production lines and for continuous heavy duty is designed to use $^3/_{16}$-in. diameter wire. Its capacities are shown in Table 2.

**Table 1—Modern Wire Gun Capacities (Hand) Using Acetylene Gas Plus Oxygen**

| | *Hand gun—Regular, —$^1/_8$-in. wire—* | | *Hand gun for corrosion applications, —$^3/_{16}$-in. wire—* | |
|---|---|---|---|---|
| *Metal* | *Metal per hour, lb.* | *Square feet covered per hour 0.010 in. thick* | *Metal per hour, lb.* | *Square feet per hour, 0.010 in. thick* |
| Aluminum | 9 | 67 | 17 | 125 |
| 5% Silicon aluminum | 10 | 70 | 19 | 140 |
| Tin babbitt | 28 | 56 | 96 | 191 |
| Lead | ... | ... | 147 | 182 |
| Red brass | 17 | 35 | ... | ... |
| Yellow brass | 20 | 42 | ... | ... |
| Phosphor bronze | 18 | 39 | ... | ... |
| Aluminum bronze | 13 | 29 | ... | ... |
| Copper | 17 | 35 | ... | ... |
| Monel | 12 | 25 | ... | ... |
| Nickel | 11 | 22 | ... | ... |
| 18–8 Stainless steel | 12 | 27 | ... | ... |
| High-carbon chrome stainless | 11 | 26 | ... | ... |
| Carbon steel | 12 | 30 | ... | ... |
| Tin | 28 | 60 | 95 | 216 |
| Zinc | 27 | 53 | 61 | 123 |
| Sprabond wire | 5 | 13 | ... | ... |
| Hard surfacing | 5 | 9 | ... | ... |

*Courtesy Metallizing Engineering Co., Inc.*

**Table 2—Modern Wire Gun Capacities (Heavy Duty) Using Acetylene Gas Plus Oxygen and $^3/_{16}$-In. Diameter Wire**

| | *—Heavy-duty gun—* | |
|---|---|---|
| *Metal* | *Metal per hour, lb.* | *Square feet covered per hour, 0.010 in. thick* |
| Aluminum | 12 | 85 |
| 5% Silicon aluminum | 16 | 113 |
| Tin babbitt | 85 | 169 |
| Red brass | 24 | 50 |
| Yellow brass | 32 | 68 |
| Phosphor bronze | 31 | 62 |
| Aluminum bronze | 24 | 54 |
| Copper | 29 | 62 |
| Monel | 17 | 34 |
| Nickel | 18 | 37 |
| 18–8 Stainless steel | 21 | 47 |
| High-carbon chromium stainless steel | 19 | 40 |
| Carbon steel | 19 | 46 |
| Tin | 47 | 109 |
| Zinc | 55 | 121 |
| Sprabond wire* | 6 | 15 |
| Hard surfacing | 9 | 16 |

* Using $^1/_8$-in. diameter wire.

*Courtesy Metallizing Engineering Co., Inc.*

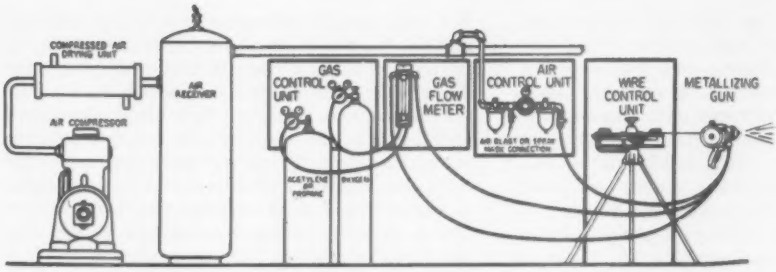


*Figure 1*

Improvements in the past ten years in auxiliary equipment for the wire gun have been many. A siphon air blast has been developed for cooling the work being metallized at less cost and with less cracking of the sprayed metal. A valve lubricant has been developed to prevent sticking, tightening, galling and scoring of valves and nozzles in the spray gun. A brush-on water-soluble masking compound has been developed to replace masking with adhesive tape, etc. Gas flow meters have been adapted to the metallizing process to give accurate control of the quantity of fuel and quantity of oxygen being fed to the gun. Improved wire control reels and straightener units have been developed for feeding the gun. Air-control units have been developed to provide clean dry air for better spraying. A health-control unit has been developed to give the operator complete protection from fumes and dust while metallizing. Magnetic thickness gages have been developed for application to sprayed metal for measuring the thickness of nonmagnetic coatings on iron or steel base. The net result of all of these developments is that now a shop can install the complete process with equipment designed for the specific work intended and management can expect uniform production from day to day. A complete metallizing installation showing the modern equipment from the compressor to the gun is illustrated in Fig. 1.

## IMPROVEMENTS IN SURFACE PREPARATION EQUIPMENT AND TECHNIQUE

Early in the history of metallizing, it was realized that a clean and roughened surface was needed to obtain adhesion of the sprayed metal coat to the base metal. Silica sandblasting was the standard method of preparation of the surfaces. As more was learned about the nature of the bond between the spray metal layer and the base metal, more attention was paid to the preparation of the surface to receive the layer. Graded abrasives of the aluminum oxide class were used and angular steel grit. Where maximum bond strength was necessary, as in the building up of bearing surfaces, etc., rough turning was resorted to early in the 1930's. Rough turning or rough threading offered advantages over sand- or gritblasting in that it provided a more adequate bond for heavier coatings and permitted preparation of circular surfaces on a lathe without the employment of blasting equipment. Obviously the rough threading operation was limited to materials which could be machined and to surfaces that were accessible to machine tools. It was limited also, to materials of such a nature as tend to tear under a cutting tool to provide many crevices in the surface to which the spray metal could adhere.

The next step in development of improved methods of surface preparation for machinable surfaces was the development of a mechanical means for producing a good bonding surface known as the Rotary Roughening Tool, developed by A. P. Shepard. This tool is used on simple and on grooved surfaces to give a much stronger bond than obtainable by sandblasting or rough threading alone. The bond resulting from the use of this tool is more consistent, is applicable to metals that do not tear under the tool during machining and is not so dependent upon the operator's judgment. It has its limitations, although it is still the best method for machinable surfaces which can be grooved, in that when used without the grooving it does not give a bond much stronger than that produced by gritblasting and also in that it is not usable on surfaces inaccessible to tooling and it cannot be applied to surfaces which are not readily machinable.

Prior to about 1942, it was not possible to prepare surfaces of hard materials to produce an adequate bond with spray metal coatings. About this time the Meduna process was developed. This process is known as the electric bond method and also referred to as fuse bond or arc bond. This process offered the answer to many of the problems of surface preparation which had been confronting the industry for some twenty years. It provides a method of preparing hard surfaces, flat surfaces, surfaces not accessible for rough turning or tooling, materials that were machinable but that did not tear under the tool. It is applicable to almost any type of metal base. It gives a high strength bond between base metal and spray metal without the use of expensive sandblast equipment, numerous machine tool setups, grooving, turning, rough threading or tooling, and makes possible the preparation of surfaces of practically any kind of metallic machine element. The development of this method of surface preparation resulted in vast increases in the field of metallizing for repair of machine elements and reclamation and salvage of parts previously considered irreparable. By a combination of

electrical resistance heating and arcing or sparking, this process deposits metal from an electrode onto the surface being prepared. The electrode metal is melted and firmly fused to the base metal in a porous, spongy form with a large number of irregularly shaped particles and cavities over its entire surface. The metal as deposited is firmly fused to and, therefore, alloyed with the base metal. It produces a surface roughness which can range from 0.004 to 0.030 in. and provides an excellent base for the adherence of spray metal Actual fusion into the base metal is of the order of only a few thousandths of an inch and is so thoroughly confined to the surface and to local areas being prepared that the base metal is not overheated in the process.

While this process offers many advantages, it is not without its disadvantages. For machine element work where fatigue resistance is of importance, this method of surface preparation is inferior to grooving and rotary roughening, tooling, gritblasting or rough threading. The process has its particular application where surfaces need to be built up to a considerable degree and where fatigue properties are not of primary consideration. As the surface irregularities produced by this process may be as large as 0.030 in., it is obvious that this process is not suitable as one for preparing a surface to receive only a few thousandths of an inch of metallized coating as required in corrosion protection applications.

The most outstanding development in connection with surface preparation has come since World War II. Over 20 years ago it was realized that in ordinary metallizing the bond between the coating applied and the base metal was due to interlocking on a roughened surface rather than due to alloying of the particles of sprayed metal with the surface being sprayed. Throughout those years it was realized that an ideal solution to the problem would be to be able to spray a metal in such a fashion as to obtain a true alloy bond between the spray particles and the surface receiving them. Many kinds of materials were tried without success. In 1948 a solution was found to the problem in the form of a special molybdenum wire, especially developed for metallizing purposes. Molybdenum has such a high melting point, about 4750° F., that it would seem impossible to have it melt in the wire gun and spray in the same way as the steels and other alloys with melting points very much lower in temperature. Since molybdenum has such a high melting point, one would expect that the particles thrown off from the end of a wire as it melted would chill very rapidly and would not travel an appreciable distance and still be in the molten state when they struck a surface. Since molybdenum oxidizes quite rapidly, one would expect that the molten particles would be converted to oxides so rapidly as not to form a good deposit from a wire gun. There is a proposal to designate this process as "metallic spray bonding."

The developing of this special molybdenum wire for metallizing proved all of these expectations wrong. Not only does this wire melt in a wire gun but the particles do not freeze before impinging upon the surface and are not covered with oxide when they do impinge. The particles impinge at such a high temperature and in such a liquid state that actual alloy bonding with the surface is obtained on many materials. The spray metal deposit from a wire gun using this special molybdenum wire forms a highly satisfactory bond on all common steels, stainless steel, Monel, nickel and chromium-nickel alloys, cast iron, cast steel, magnesium and most aluminum alloys. It provides a fair bond to lead, tin, zinc and galvanized iron. It does not bond properly to copper, brass, bronze, chrome plate or Duriron. It bonds to clean glass and ceramics at room temperature, but the thermal shock, due to its high melting point, limits its use in this field.

Sprayed molybdenum coats are generally used as a bonding coat for the subsequent application of other sprayed metals. In appearance the coat is similar to that of other sprayed metals, although somewhat finer in texture and in such form that it provides a perfect surface for the application of any other type of sprayed metal upon it.

Everything must have its limitations and so also there are limitations to what can be done with sprayed molybdenum bonding. It is not a satisfactory preparation for the application of subsequent spray metal coats that are to be fused in place. It does not remove the necessity for threading, grooving, tooling, fused-bond coating and undercutting where the final spray metal application is to be over 0.50 in. thick near an edge or at a keyway. Some sprayed metals have high shrinkage as sprayed, such is the case with low-carbon steel and with the 18–8 austenitic stainless steels. In these cases molybdenum spraying can be used as a subsequent preparation on top of a previously grooved surface. Although a metallic spray bonding will adhere to a smooth surface, it will not bond adequately to a surface which is not clean and dry. All grease, cutting lubricants and moisture must be absent from the surface to obtain a good bond. To produce a satisfactory molybdenum spray from a wire gun, the oxygen and acetylene supplied to the gun must be capable of accurate control. Only because of the developments during the past 10 years of improvements in wire guns and improvements in control of oxygen and acetylene as fed to the gun has this development of molybdenum spraying been made possible.

In addition to its use as a bonding coat, sprayed molybdenum has found use in the repairing of cracked engine blocks, heads and similar castings, in repairing of casting defects, in repairing damaged lathe ways, in repairing permanent mold patterns and match plates, in applying strong and wear-resistant coatings to aluminum and magnesium alloys and in providing a means of preparing the surfaces of aluminum and magnesium alloys to receive ordinary soft solder.

In connection with metallizing for corrosion protection of iron and steel where a molybdenum bonding may be too expensive, a steel flash bonding coat has been developed. A steel flash bonding coat improves the bond of zinc or aluminum to a gritblasted steel surface. This is proving of great value in installations where the sand- or gritblasting must be done outdoors where heavy and adequate gritblasting is next to impossible. The steel flash bond coat consists of spraying from 0.0005 to 0.002 in. thickness of low-carbon steel directly on the blasted surface before applying the zinc or aluminum corrosion-protection coat. The steel flash coating so applied is not a completely continuous coat but is sufficient to provide a firm anchorage for the corrosion protection coat of sprayed zinc or sprayed aluminum to be applied on top of it. The steel flash bonding coat is of great value when used under a sprayed zinc coat over 0.010 in. thick or a sprayed aluminum coat over 0.008 in. thick. Where edge effects are of importance, it has been found that a steel flash bonding coat sprayed around the edges and corners only improves the bond at these places. The added bond strength obtained by the use of a steel flash bonding coat under either aluminum or zinc applied for corrosion protection has been found sufficient to effectively prevent blistering of the aluminum or zinc coat in both salt and fresh water applications.

## IMPROVEMENTS IN TYPES OF COATINGS

Improvements in the types of metal coatings applied by the metallizing process have been along the lines of heat-resisting, corrosion-resisting and wear-resisting coatings. To provide steel with a heat- or oxidation-resistant surface, a number of aluminizing processes were developed many years ago. The aluminizing was obtained by dipping in molten aluminum, tumbling at an elevated temperature in a mix of aluminum metal granules and aluminum oxide and various modifications of these two processes. Attempts were made to accomplish the purpose or the same results by the application of aluminum flake paint followed by heating. Some years later it was found that aluminum could be sprayed upon the surface from a wire spray gun. The modern development in connection with aluminized surfaces for protection against oxidation consists of a process of metallizing the surface of the steel with a coating of aluminum, applying a sealing coat of a paint-type of vehicle carrying aluminum flake, followed by heating in air to fuse the coating in place. This type of heat-resisting coating offers good protection for temperatures up to 1600° F. and is an inexpensive and satisfactory method of protecting iron or steel surfaces from the corrosive action of hot gases.

For temperature protection in the ranges of 1600 to 1800° F., where large amounts of sulphur are not present in the gases, a special chromium-nickel alloy can be sprayed on the steel surface and then coated with a special sealer containing metallic aluminum flakes. In this case, no heat treatment is required since the sprayed coat plus the aluminum flakes become alloyed in the first heat when the part is put in use. For temperatures above 1800° F. or where strong sulphur gases are present, a protective coat is obtained by spraying a chromium-nickel alloy followed by spraying pure aluminum followed by the application of a sealer coat of a vehicle containing aluminum pigment. When put into operation the spray metal combination forms an alloy. This alloy consists of chromium-nickel-aluminum and iron. The amount of aluminum is sufficient to alloy with the previously sprayed metal and the base metal to form a composite coat of high heat resistance.

The above coatings as originally finished or as the result of service are essentially fused coatings that are dependent upon the ability of aluminum to alloy with many metals and to offer protection against oxidation at elevated temperatures. A further development in connection with fused metal coatings for heat resistance, corrosion resistance and wear resistance is in the form of fused hard-facing alloys. Cobalt-chromium-nickel alloys are recognized as alloys of high hardness and wear resistance and high resistance to temperatures and to corrosive media. The alloys most suitable, from the standpoint of hard facing, for wear resistance are too hard and brittle to be producible in the form of wire for use in a wire spray gun. They can be produced in powder form. The development of plastic bonded wire made the application of these hard wear- and corrosion-resistant coatings possible by means of a wire gun. The powdered alloy of suitable composition is mixed with a powdered plastic binder and extruded into the form of wire. The plastic binding material represents but a fraction of the weight of the finished wire and is volatilized completely in the metallizing gun while the powdered metallic portion of the wire is deposited on the surface being sprayed. This deposit on the surface is then fused in place by use of suitable fusing techniques; either torch or furnace methods may be used. The result is a fused-in-place coating of the desired composition and of the desired thickness. In this way, a hard coating of great wear and corrosion resistance can be applied to specific areas where required.

An alloy which can be fused in place in this fashion to produce a smooth, dense coating firmly alloyed with the base metal is one of the modern developments. The requirements for the metal for this purpose were that it should be sprayable, that it should be fusible at a temperature low enough not to be excessive for the steel upon which it was being sprayed, that it could be fused in place without excessive slagging and oxidation and that it would congeal or freeze without cracking. The cobalt-nickel-chromium-iron-boron-silicon alloy developed for this purpose has a melting point slightly below 2000° F., is self-fluxing in the molten condition so as to form a true alloying with the steel surface without entrapping large quantities of oxide and slag and forms a smooth coating with a Rockwell C

**Table 3—Sprayed Metal Coatings for Heat Resistance**

| *Temperature range and conditions* | *Coatings* | *Treatment* |
|---|---|---|
| Up to 1600° F. | Sprayed aluminum plus aluminum flake | Fused |
| 1600° to 1800° F., no sulphur | Sprayed chromium-nickel alloy plus aluminum flake | None |
| 1600 to 1800° F. with sulphur or above 1800° F. | Sprayed chromium-nickel alloy plus sprayed aluminum plus aluminum flake | None |
| Up to 1600° F. plus wear | Cobalt-chromium-nickel alloy | Fused |

hardness of around 50. In addition to high wear resistance, as required of a hard-facing material, the coatings formed in this way have high corrosion resistance and high resistance to oxidation at elevated temperatures. Sprayed metal coatings for heat resistance are shown in Table 3.

For wear resistance purposes, the sprayed molybdenum coatings, as first developed for bonding only, are proving of considerable value. A molybdenum-sprayed surface provides an excellent bearing surface for many applications. It is finding good use with bronze bearings where abrasive conditions are severe. It is being used extensively for building up of worn spindles on grinding machines, on aluminum and iron brake drums such as are used on elevators and presses, for salvage of press fit sections on shafts, crankshaft flange areas, etc. It is not recommended for high temperature applications.

Many other types of coatings have been developed during the past ten years. Special alloys in wire form have been developed. An iron-containing aluminum bronze with good sprayability and yielding a good finished surface of high strength, wear and corrosion resistance is now available. Tobin or Navel bronze, phosphor bronze, commercial bronze or brass in wire form and tailored for metallizing purposes can be used. Lead babbitts or tin babbitts in wire form are available as well as nickel and Monel metal, lead, zinc, tin, aluminum and copper where these metals are indicated. Austenitic stainless steels or high-carbon, high-chromium wear-resistant steels or plain carbon steels of various carbon content from a low carbon to a high carbon can be sprayed. Each wire of each composition as sprayed produces its particular type of coating suitable for its particular special application.

## MECHANICAL PROPERTIES OF SPRAYED METAL COATING

Sprayed metal or metallized coatings produced by the metallizing process differ considerably both chemically and physically from the original wire used in the wire gun to produce the metal spray. While the mechanism of the bond between sprayed metal and base metal and the mechanism of the bond between the individual particles of sprayed metal are not fully understood a great deal has been learned about them. A sprayed metal deposit consists of many individual particles with certain mechanical interlocks, a small amount of welding or alloy bonding between minute portions of particles, and attachment through joint oxide layers between particles. The over-all properties of the sprayed metal must, therefore, be a composite of the properties of the metal particles themselves, the degree of attachment between individual particles, the properties of the oxide layers between particles and the degree of porosity within the structure. Normally metals are rated according to their density, hardness, tensile strength and ductility. To determine these properties with respect to sprayed metal deposits, it has been necessary to develop specialized methods of test. The strength of the bond between a metallized layer or coating and the base metal is of great importance and it has been necessary to develop special test procedures and techniques in order to determine the strength of bond obtained between various combinations of metals and surface preparation. Technical data of this kind are necessary for the intelligent engineering application of sprayed metal coats in industry. Technical information of this kind has been developed in considerable detail during the past ten years.

The specific gravity of sprayed metal may be between 85 and 95% of the specific gravity of the metal in the original wire form. Since sprayed metal deposits contain considerable metal oxide and since metal oxides have lower specific gravity than the metal from which they came, the difference in specific gravity between sprayed metal and the original metal is not a true indication of the degree of porosity of the sprayed metal itself. Actually, the sprayed metal is much less porous than would be indicated by the 5 to 15% loss in specific gravity. Indications are that the actual porosity or vacant space in sprayed metal deposits may be less than 5%.

Hardness of sprayed metal deposits as determined by the ordinary indentation hardness methods, Rockwell, Brinell, etc., is misleading. The hardness figures obtained by these tests are influenced by the hardness of the metal particles themselves, the bond between particles, the porosity of the deposit and the friable nature of the oxide films within the deposit. While hardness tests are used to compare one sprayed metal with another, in some cases they can lead to questionable conclusions. Micro-hardness determinations of the individual particles of metal within a sprayed metal mass give results that are radically different from the over-all indentation hardness figures obtained by the use of the Rockwell testing technique. For example, an 0.80 carbon steel as sprayed shows an ordinary Rockwell hardness of approximately C-36 whereas microhardness tests show that the individual particles have hardnesses approaching C-66. From a wear-resisting standpoint, the ordinary Rockwell hardness determination on a sprayed metal deposit should not be compared to a Rockwell hardness determination on a piece of wrought metal. Thus, an 0.80% carbon steel as sprayed with an apparent Rockwell hardness of

only C-36 will show the wear resistance under non-lubrication conditions of a hardened high-carbon steel at a Rockwell hardness above C-60. Where lubrication is present, the slight porosity of the sprayed steel is of assistance and the sprayed 0.80% carbon steel is found to resist wear much better than hardened high-carbon steel.

The over-all tensile strength of a metal is of prime importance. To the extent that a metal is stressed internally in tension, it will have less strength available to withstand a tension stress applied to it externally. The determination of internal stresses in sprayed metal deposits is quite difficult. One approach to this problem of internal stresses has been a determination of the tendency of the sprayed deposit to shrink as it is built up. Each layer of sprayed metal is applied at a temperature in the neighborhood of the melting point of the metal being sprayed. Immediately after the layer is formed, it begins to cool and in this cooling shrinks a certain amount. In this shrinkage it develops internal tension stresses of a biaxial nature in the plane of the surface as sprayed. As each individual layer is deposited upon the previously stressed layers, this new individual layer sets up its stress. The heat resulting from the application of successive layers during the spraying process tends to release some of the stress in the previously deposited coatings. The net result is that the coating as finally built up to the desired thickness has higher biaxial tension stresses near its top surface than near the base metal surface underneath the coating. This nonuniform stress distribution within the sprayed metal coating is an internal stress which tends to lift the edges of the coating away from flat surfaces and at the edges of keyways in shafts. The over-all average internal residual stress is such as to cause the coating to be held tighter when applied to a cylindrical shape but tends to pull the coating away when applied to the inner bore surface of a cylinder.

Test methods have been developed for determining comparative shrinkage characteristics of various metals when sprayed. The values obtained are inversely related to the residual stresses in the sprayed metal The tests determine the comparative shrinkage in terms of thousandths of an inch per inch of coating as deposited upon a flat surface. These tests show that in plain carbon steel a minimum amount of shrinkage tendency is obtained with a steel containing 0.80% of carbon and the shrinkage tendency goes up rapidly as the carbon content is reduced. Similarly, they show that a minimum amount of shrinkage tendency is present in high-carbon, high-chromium stainless steel but a maximum amount in the austenitic 18–8 stainless steels. Among the bronzes, the aluminum bronzes have lower shrinkage tendency than the other bronzes. Molybdenum spray has been found to have a much lower tendency toward shrinkage than the austenitic stainless steels, although approximately twice the tendency of the 0.80% plain carbon steel or the high carbon, high-chromium stainless steels.

The specific knowledge gained by the investigation of internal stresses in spray metal deposits has been of great assistance in the development of better techniques of spraying to produce superior coatings. With this better understanding of what goes on in the process of metallizing it has been possible to develop the process to its present stage where uniformity of deposits from day to day can be assured.

As stated previously, the over-all tensile strength of a sprayed metal deposit is affected by residual stresses from the metallizing procedure as well as being a composite of strengths of mechanical interlocks between particles and cohesiveness of oxide films. Methods of determining tensile strength of sprayed metal have been developed. The final method arrived at consisted of spraying the metal on a thin steel tube and then machining away the inner steel tube so that the actual tensile test could be made on sprayed metal alone. In this way, it was possible to determine both the ultimate strength and the elongation under load at failure. The results of such tests are interesting and are shown in Table 4. For example, sprayed austenitic stainless steel, soft iron, steel containing 0.10% carbon and aluminum bronze all have ultimate strengths as sprayed of the order of 28,000 to 30,000 psi. High-carbon, high-chromium steel as sprayed has a tensile strength of the order of 40,000 psi., whereas 0.80% carbon steel has a tensile strength of 27,500 psi. Sprayed aluminum has greater tensile strength than the wrought material. Sprayed 99% aluminum shows a tensile strength of 19,500 psi., whereas a sprayed aluminum alloy containing 5% silicon–95% aluminum shows an ultimate tensile strength of 37,000 psi. which is higher than that obtainable by any method of casting this alloy. Sprayed zinc shows an ultimate tensile strength of 13,000 psi. which is much higher than any tensile strength normally found for unalloyed zinc metal. The elongation under load before fracture of sprayed metal is approximately 0.25 to 0.50% with the exception of sprayed zinc where elongations under load of 1.40% are obtained.

The bond between sprayed metal and base metal is of vital importance in a majority of applications and is one of the mechanical properties most difficult to

**Table 4—Properties of Sprayed Metal Coatings**

| *Metal* | *Shrinkage, in. per in.* | *Tensile strength, psi.* | *Extension under load, %* |
|---|---|---|---|
| 18–8 austenitic stainless steel | 0.012 | 30,000 | 0.27 |
| High-carbon chromium stainless steel | 0.0018 | 40,000 | 0.50 |
| 0.10-carbon steel | 0.008 | 30,000 | 0.30 |
| 0.25-carbon steel | 0.006 | 34,700 | 0.46 |
| 0.80-carbon steel | 0.0014 | 27,500 | 0.42 |
| Aluminum | 0.0068 | 19,500 | 0.23 |
| 5% Silicon–95% aluminum | 0.0057 | 37,000 | 0.54 |
| Aluminum bronze | 0.0055 | 29,000 | 0.46 |
| Phosphor bronze | 0.010 | 18,000 | 0.35 |
| Zinc | 0.010 | 13,000 | 1.43 |
| Sprabond wire | 0.003 | 7,500 | 0.30 |

*Courtesy Metallizing Engineering Co., Inc.*

measure. Bond strength in shear is of importance as also is bond strength measured perpendicular to the interface between sprayed metal and base metal. This latter can be termed "bond strength in tension" between the metallized coating and the base metal. With the inferior or less desirable methods of surface preparation, perpendicular or tension bond strength may be below 1000 psi. With the improved methods of surface preparation as with grooving and tooling or fusion bonding or molybdenum wire bonding, the perpendicular or tension bond strength may be of the order of 3000 psi. or higher. Similarly, the shear strength may go from less than 2000 psi. to strengths of 10,000 lb. or more per square inch. A subcommittee of the A.W.S. Metallizing Committee is developing standardized methods of testing for the mechanical properties of sprayed coatings.

## METALLIZING FOR CORROSION PROTECTION

Metallizing has been used for corrosion protection purposes for over 30 years, it is not a modern development. However, modern improvements in the wire gun, in methods of surface preparation and in formulations of alloys in wire form for use in wire guns have resulted in a vast extension of the field of application of metallizing for corrosion protection. One of the greatest forward-looking steps is the realization that sprayed metal surfaces are excellent bases for the application of organic coatings and that the protection offered by an organic coating can be extended several-fold by the use of an undercoat of metallized zinc or of aluminum. This has led to the development of special organic sealing and top coating formulations particularly and peculiarly compatible with spray metal undercoats. Today metallizing can be considered as truly competitive to galvanizing, either electro-galvanizing or hot dip galvanizing. Metallizing alone is superior to and longer corrosion protection is provided by it than when ordinary simple oil paints are used. Metallizing alone is competitive with the most expensive and complicated multiple-coat paint systems available. The combination of a metallized undercoat plus especially formulated seal and organic resin topcoats provide corrosion protection superior to anything obtainable to date by organic systems applied directly to steel. It is common to consider the protection offered to iron and steel by various paint systems in terms of two, three, five or seven years maximum period between repaintings. The protection offered by metallizing is considered in terms of five, ten, twenty or more years. These differences in expected life are so phenomenal as to be looked upon with great skepticism. Although this order of protection against corrosion is confirmed by many case histories both in this country and Europe, there is need for more authentic information.

This need for authentic information regarding the corrosion protection offered by various thicknesses of sprayed zinc, by various thicknesses of sprayed aluminum, and by these same thicknesses combined with sealing coats of organic materials plus topcoats of organic materials has been recognized by the Metallizing Committee of the AMERICAN WELDING SOCIETY. Its Subcommittee III on Corrosion Applications has formulated an extensive program of testing which is calculated to yield the authentic unbiased information needed in this field. The program involves the preparation of over 4500 panels of steel to be exposed at many different locations. For both atmospheric and sea water exposure these steel panels will carry coating thicknesses of 0.003, 0.006, 0.009, 0.012 and 0.015 in. of metal. Panels metallized with these thicknesses of zinc and panels metallized with these thicknesses of aluminum will be prepared. The program includes various methods of surface preparation prior to the application of these coatings. The program includes the exposure of metallized panels without sealing coats and without topcoats as well as with these types of coats.

The atmospheric exposure program, as well as the sea water exposure program, is to be carried out with the cooperation of the American Society for Testing Materials. The test panels will be exposed at many of the test sites arranged for and maintained by the A.S.T.M. For marine atmospheres, test sites at Kure Beach, N. C., on the Gulf Coast and near San Francisco are planned. For industrial atmospheric exposure, test sites in New York City, Columbus, Ohio, and in the Chicago area are planned. Sea water exposures are being arranged for at Wrightsville, North Carolina, and on the Gulf Coast. For mounting of the individual specimens at the various locations, some 128 special racks are being built by one of the firms cooperating in the program. The steel necessary for the panels is being contributed by another firm cooperating in the program. The surface preparation, metallizing and coating of the panels, is being done by another volunteer worker on the program. A small fund is being collected with which to purchase the necessary porcelain insulators, nuts and bolts required for mounting the specimens and with which to defray the packing and shipping charges for transporting the racks and specimens to and from the various locations. This fund represents but a very small percentage of the actual total cost of the program in time and materials.

Within the next six or eight months, it is expected that the racks and specimens will be shipped to their various locations and placed on exposure. Complete sets of specimens will be removed after one year and examined in detail. The next set of specimens is scheduled to be removed after three years exposure, and similarly examined. The third set will be removed after six years and the fourth set after twelve years. During the progress of the program, reports will be prepared and will be available through the AMERICAN WELDING SOCIETY to all those who are interested. It is expected that the Metallizing Committee of the AMERICAN WELDING SOCIETY will proceed with the

preparation and issuing of recommended practices in connection with metallizing for corrosion protection. In the meantime, attention is called to the recommended practices with respect to metallizing already issued and available from the AMERICAN WELDING SOCIETY which cover many of the aspects of metallizing discussed in this paper. They are: Part IA—Metallizing Shafts or Similar Objects, and Part II—Metallizing—Safety Recommendations.


## ACKNOWLEDGMENTS

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# Seam Welding Containers Automatically

### *Discussion by R. H. Blair*

DUE to the wide experience of Mr. Seltzer on this very specialized subject, the writer is limiting the following comments to the welding operation and omitting the stock handling and forming problems.

Assuming that the start and end condition of the container weld is to be held uniform, it seems that the use of synchronous control would not be as satisfactory as an ignitron contractor-heat control combination for weld consistency at the start and finish. The synchronous control operates on a lead and trail tube firing arrangement so that it may be necessary to delay firing by a half cycle while waiting for the lead tube to fire; likewise, on the end of the weld, it may be necessary to take a half cycle more weld current than desired in order to permit the trail tube to complete the sequence. The higher the weld speed, the more important this condition becomes. Nonsynchronous action, however, will start the weld when initiation circuit is closed and complete the weld within the half cycle in which the initiation is opened. The transient caused by this latter method is very slightly felt in the secondary current and its duration is for only the first half cycle due to an apparent change in frequency, the degree of apparent frequency change being dependent on the power factor of the machine.

High-speed seam welding of containers has an analogy in high-speed tube welding where a.-c. welding of either is limited by the spacing of half-cycle welds required to maintain a weld overlap. This speed is generally accepted to be 60 ft. per minute for 60-cycle current and 180 ft. per minute for 180-cycle current. This represents the upper limit for overlap welds at the above frequencies and would apply regardless of the product. In line with Mr. Seltzer's finding on full-wave, three-phase rectification for increased weld speed, recent findings in d.-c. welding of tubing showed an 884% increase in speed over 60-cycle welding and a 295% increase in speed over 180-cycle welding when using three-phase, full-wave rectification on those stock thicknesses that were normally "spot-spacing limited" on a.-c. welding. Also, these d.-c. weld speeds were limited to the above speeds through current limitation and not ripple frequency.

The above analogy is mentioned to illustrate the possibility of much higher weld speeds in container welding providing the problem of faster stock handling can accompany the higher d.-c. weld speeds. Starting and stopping the weld current accurately for container welding for weld speeds in the 500 ft. per minute magnitude would, undoubtedly, be a problem in itself and probably weld speeds of this magnitude are reserved for continuous duty cycle operation.

Mr. Seltzer has rightly emphasized the importance of lap consistency on a.-c. welding. This factor would still be important on d.-c. welds using rectifiers having the inverse resistance-current relationship but the degree of importance of lap consistency would be noticeably reduced. Good machine design would concentrate the major portion of the resistance external to the rectification unit in the lap itself so that the weld current would tend to automatically alter its magnitude to suit the lap variations.

This latter characteristic of rectifier-type welding provides a semiautomatic control of the weld current and should be quite applicable to exceptionally high-speed seam welding where short-period scrap runs could be very expensive.


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# Schlieren Analysis of Inert-Gas Arc Shields

***A visible method of comparing helium and argon arc shields win nonconsumable electrode equipment***

*by W. B. Moen and G. J. Gibson*

**Abstract**

The schlieren method of making gases visible was applied to a comparison study of helium and argon as arc shields with non-consumable electrode equipment. The results indicate that either gas will provide adequate coverage and the choice of gas depends only upon the desired electrical characteristics and economics.

A brief explanation of the schlieren apparatus applied to this study and a number of photographs substantiating the results are included.

## INTRODUCTION

SINCE the inception of the inert-gas shielded-arc-welding process many arguments have been advanced attempting to confirm the superiority of one gas over another. Most of the discussion has not been confined to an analysis of any one particular phase of the subject, but instead has endeavored to evaluate the over-all desirability of either helium or argon. A logical investigation of the problem includes studies of the electrical characteristics, economics and fluid dynamics, and it is this last subject with which this article is concerned.

Optical methods of viewing the gas shield supplemented by a logical interpretation of the results with cognizance taken of the physical properties of the gases have pointed to the fact that either helium or argon provides a satisfactory shield when examined only from the fluid-dynamics aspect. The justification of this conclusion, apparatus used and the test procedures are described herein. The test procedure is limited to equipment using a non-consumable electrode.

## SCHLIEREN APPARATUS

Early developments in inert arc welding pointed to the need for a method permitting visualization of the path of the shielding gas as it issues from the gas nozzle. Information obtained in this manner is extremely useful both in the development of effective geometric designs, and in the investigation of the performance of the gas shield. Three general experimental methods were considered:

1. Introduction of smoke or particles into the gas stream to show the stream direction and extent. Difficulties in controlling the tracing medium eliminated further consideration of this approach.

2. Traversing probes which would indicate both the purity and the direction of the stream. The large amount of experimental labor required plus the disturbance caused by the introduction of a probe into the gas stream made this method rather impractical.

3. Optical techniques dependent upon density changes due to variations of composition, temperature and pressure of the gas under investigation. With these techniques the changes, by means of their attendant changes of the index of refraction can be made visible and recorded photographically. The final choice fell upon the schlieren technique because it is a proven experimental method that has been applied to other gas flow problems and required few modifications to provide satisfactory results.

Although elaborate descriptions of the theory and operation of the schlieren method may be found in the literature,[1] a brief explanation of the principle and equipment, with the aid of Figs. 1 and 2, may not be out of place.

An effective light source, formed by a rotatable slit approximately 0.010 x 0.040 in., is located at the focal point of the first mirror. The General Electric schlieren light source comprises a tungsten ribbon filament lamp as a steady state source used for alignment, observation and time exposures; and a 5-microsecond duration flash tube which is synchronized with the camera shutter. Both lamps are aligned so that the slit is evenly illuminated and functions as the effective light source. After striking the first mirror (a 12-in. diameter, first surface, parabolic type), the light is reflected in a parallel beam of circular cross section in which the phenomenon to be studied is located. The light beam, next striking an identical second mirror is reflected, still in a horizontal plane, to the rotatable knife edge where an image of the slit light source is formed. The remainder of the optical receiving system consists of focusing and magnifying elements, a central shutter with a $^1/_{800}$-sec. maximum speed and a film holder.

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[1] "Bibliography on High Speed Photography, Part 5—Schlieren," *Jl. Soc. Mot. Pict. and Television Engrs.*, **57** (3) 146–147 (1951).

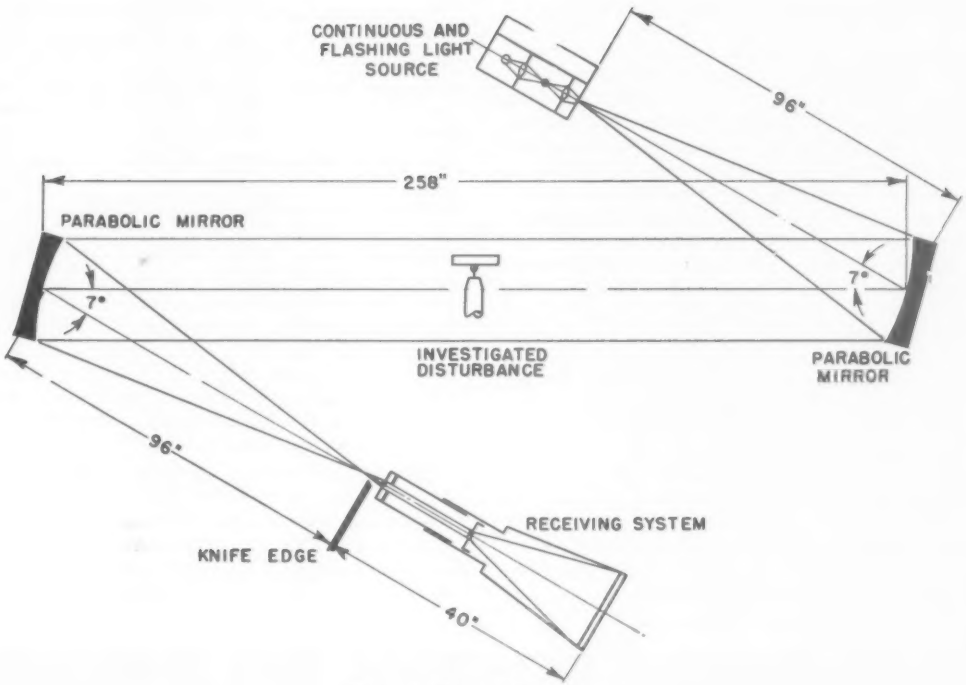


*Fig. 1 Schlieren optical system*

When the knife edge is at the correct location and is made to intercept the image of the slit light source, the field as viewed on a screen is uniformly darkened. Now if some disturbance such as a nozzle issuing a shield gas is placed in the path of the parallel beam in a region where no overlapping of light rays occurs, some of the normally parallel rays will be deflected because the index of refraction of the disturbance is different from that of the ambient still air. These deflected rays will now strike the second mirror at some point other than their original location and when reflected will either be intercepted by or pass over the knife edge and indicate the flow pattern on the viewing screen. The slit light source and knife edge, which should have their long dimensions parallel, are rotatable so that either vertical or horizontal disturbances may be viewed.

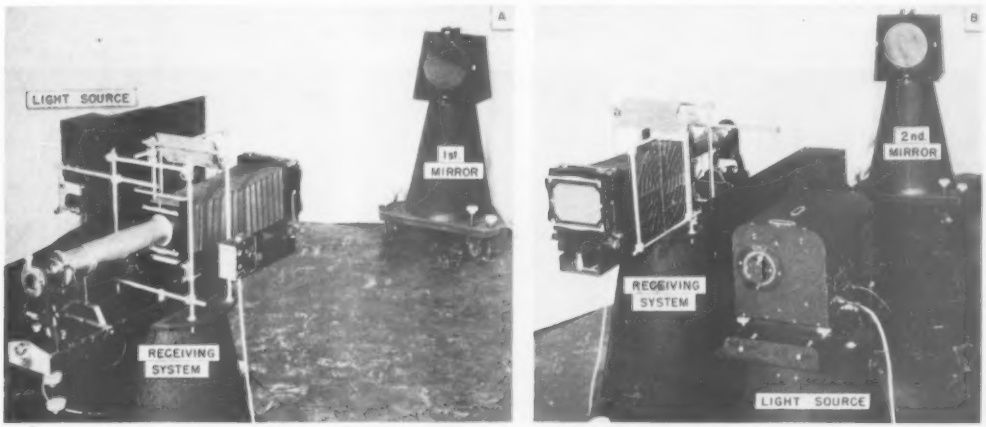


*Fig. 2 Schlieren equipment*

## TEST CONDITIONS AND PROCEDURE

There are so many factors that enter into an analysis of the flow from a nozzle while welding that extreme care must be taken so that the results will not be clouded by inconsistencies in the comparative test procedure. In any schlieren analysis two procedures must be described, the optical technique and a description of the apparatus being investigated. All the photographs shown here were made with the long dimension of the schlieren slit light source and knife edge perpendicular to the direction of flow from the nozzle so that disturbances along the length of the axis of the electrode holder were viewed. A few exposures were made with the rotatable components turned parallel to the axis of flow but no significant difference in defining gas coverage limitations was noted. Furthermore, all photographs, whether with or without an arc, were taken with the 5 microsecond duration schlieren light source flash and the shutter at its maximum speed. This high speed light source effectively stops the transient flow condition and the camera shutter controls the exposure from the arc. Photographs taken at lower speeds give an averaging result that is not indicative of the effectiveness of the gas shield. Relative locations of all the schlieren elements were held constant.

The welding equipment used was a standard Airco H-35 Heliweld holder with a $^1/_4$-in. protrusion of the $^1/_{16}$-in. thoriated-tungsten electrode. Workpiece to nozzle exit distance was held constant at $^7/_{16}$ in. All arcs were drawn on a $^3/_8$-in. thick stainless steel workpiece in still air.

As a basis for comparison of both gases it was decided that a flat welding position with an arc current of 75 amp., and a gas flow of 10 cfh. through a standard $^3/_8$-in. diameter convergent nozzle on a cold plate would serve best. A cold plate is defined as one in which the arc is drawn to the work originally at ambient temperature and allowing 5 sec. to elapse before the exposure is made. These two basic pictures are shown in Fig. 3, (*a*) and (*b*). Also shown in this composite are the effects of welding position on coverage. Other operational variables that change the appearance of the gas shield are illustrated in Fig. 4 and should be compared with Fig. 3, (*a*) and (*b*).

One difficulty encountered in visualizing the gas issuing from the nozzle is the confusion caused by the gas striking the workpiece. This was overcome by inverting the holder and maintaining an arc on a $^1/_8$-in. diameter water-cooled tube which offered a minimum of stream disturbance in the plane of view as shown in Fig. 5.

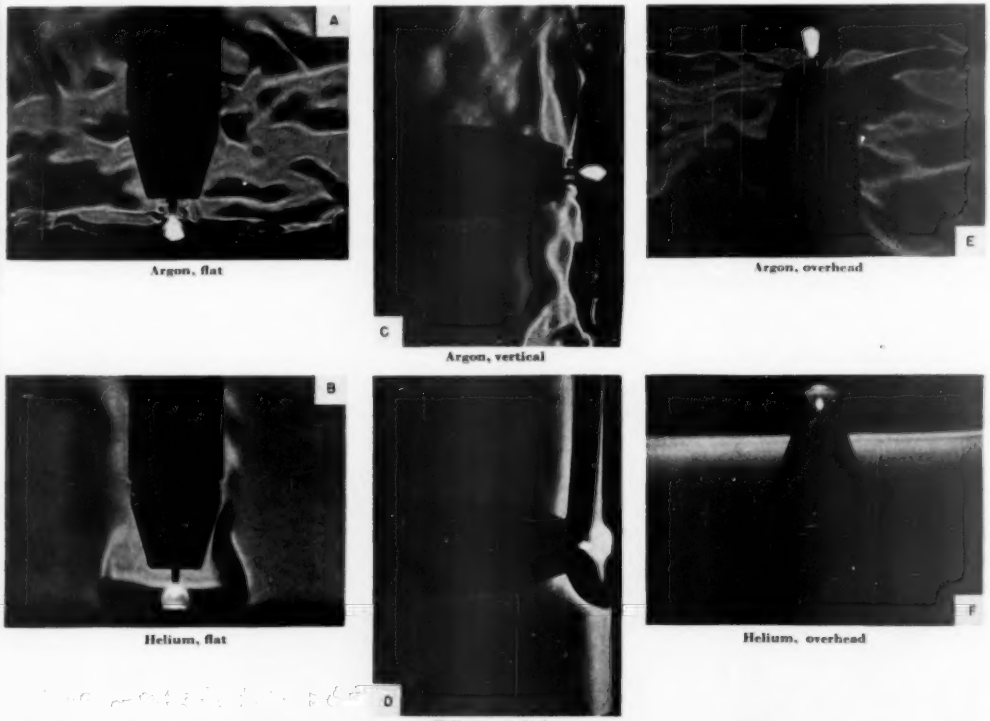


*Fig. 3 Effect of welding position on flow patterns of argon and helium, 10 cfh. gas flow, cold plate, $^3/_8$-in. diameter nozzle, 75-amp. arc current*

## RESULTS

An examination of any schlieren photograph reveals that all geometric objects show up in profile whereas the striations of the gases are indicated as a composite of shaded light and dark areas. These light and dark areas are caused by differences of the index of refraction within the disturbance. These refraction changes are due to the presence of other gases or different temperatures and pressures. Thus boundaries between two different gases and also variations in density within a single gas are observable. Since the parallel light path passes through the rebound gas and disturbed air as well as the columnar gas stream issuing from the nozzle the photographs are a composite of the above three effects. However, a close observation of a few of the photographs shows the stream issuing from the nozzle.

A comparison of Fig. 3, (*a*) and (*b*) showing the flow patterns in the flat welding position with normal operating conditions indicates that helium and argon exhibit entirely different characteristics:

1. The volume of disturbance with argon is greater than that with helium.

2. The degree of turbulence with argon is greater than that with helium.

3. The arc appearance with argon has the characteristic cone shape, whereas the helium arc has the conventional umbrella profile.

An interpretation of the performance of the shielding gases as shown in the photographs requires consideration of a few physical properties given in Table 1.

**Table 1 Pertinent Physical Properties of Shielding Gases and Air**

| | *Property* | *Argon* | *Helium* | *Air* |
|---|---|---|---|---|
| 1. | Density (lb./cu. ft.) at 70° F. and 1 atm. | 0.1034 | 0.0103 | 0.0749 |
| 2. | Heat capacity (Btu./lb./° F.) at constant pressure and 70° F. | 0.125 | 1.250 | 0.241 |
| 3. | Absolute viscosity ($10^6$ lb./ft.-sec.) at 70° F. and 1 atm. | 1.484 | 1.238 | 1.175 |
| 4. | Thermal conductivity (Btu./hr.-sq. ft.-° F.-ft.) at 70° F. and 1 atm. | 0.0097 | 0.084 | 0.0149 |

It will be noted that the only property in which the value for argon is greater than for helium is the density, whereas the value of heat capacity and thermal conductivity of helium are higher and are in the ratio of about ten to one. The viscosities are very nearly equal. The most significant property affecting flow conditions is the density-viscosity ratio and the magnitude of this ratio for argon is about eight times that of the helium ratio. These are the properties at 70° F. and the absolute values will change with an increase in temperature. All the properties except density increase with temperature. The ratios of the property values for the two gases are approximately constant as the temperature increases.

The large differences in the flow patterns of helium and argon may be explained in the following manner. Although it is true that argon has the same density as that of air at about 275° F. the whole mass of argon surrounding the arc is not heated to that temperature. That portion immediately adjacent to the arc is heated far above 275° F. causing it to rise, while that issuing at the nozzle periphery is not appreciably heated because of its low thermal conductivity and tends to spill over the work. These large density differences produce convection currents in the whole mass and show up as a large volume with a high degree of turbulence and consequent entrainment of air. The more compact pattern produced by helium, because of its greater thermal conductivity, is the result of a more uniform temperature distribution in the entire gas shield. The convection currents produced do not buck the periphery of the shield as is the case with argon, since even though the envelope is cooler than the core, its density is still far less than that of air and the whole mass rises. Consequently the turbulent region indicated in the argon case is not duplicated with helium. In addition to the effects produced by the arc, the unimpeded argon laminar gas stream issuing from the nozzle will break up into turbulence much closer to the exit than will helium because the Reynolds number of the flowing argon within the same nozzle's confines and for equal flows is approximately eight times greater than for helium.

In spite of this detailed explanation of the causes of the resultant pattern, the interest in shielding effects is only in the weld area. The helium pattern allows simple definition of the limits and results in an uncontaminated coverage diameter of about $1^1/_2$ in. Argon, although more difficult to interpret, shows an undisturbed region of the same magnitude on the surface. This then permits the conclusion that both helium and argon provide adequate shields in still air for the same gas flows.

The above observations are substantiated by inspection of the comparative photographs of other welding positions, Fig. 3, (*c*) to (*f*). In the vertical position argon appears to surround the arc symmetrically with greater turbulence closer to the underside, probably caused by the aforementioned rising convection currents. Helium, in this position, because of its greater density, gives the minimum radius coverage on the underside, about $^5/_8$-in., but this is still large enough for adequate protection. If argon had the tendency to hug the plate in the flat position, overhead welding with argon would indicate the shield falling away from the work. However, Fig. 3 (*e*) contradicts this reasoning.

The effect of increased gas flow is shown in Fig. 4, (*a*) and (*b*) and should be compared with the basic conditions shown in Fig. 3, (*a*) and (*b*). Argon, because of the greater mass to be heated does not rise as far, but the higher velocity results in a greater intensity of turbulence along the plate without an increase in coverage. The helium pattern is not appreciably

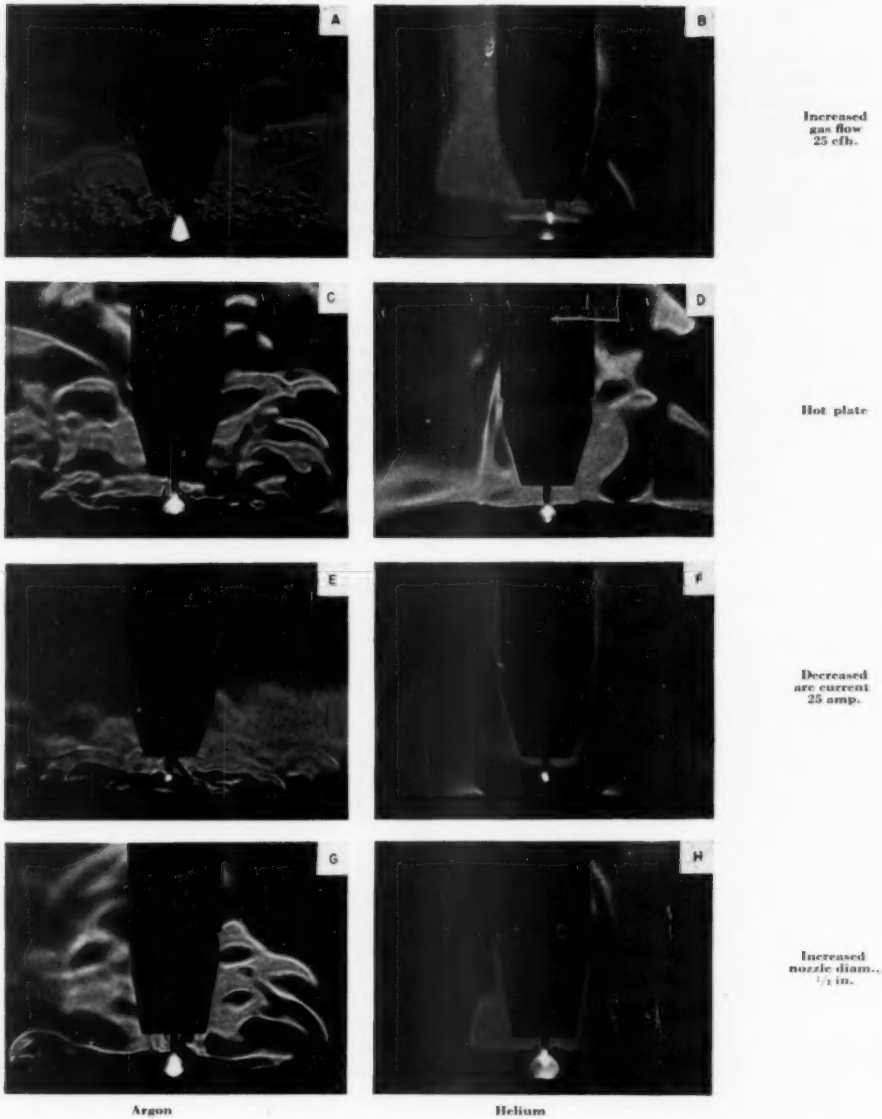


*Fig. 4 Effects of variables on flow pattern in flat position*

changed except for an increase in size. However, this should not be interpreted as signifying a need for a greater helium than argon flow for the same welding conditions because the lower flow does provide sufficient area of coverage.

Fig. 4, (*c*) and (*d*) were made with all conditions constant except for the workpiece temperature. Here the arc was maintained for a period of about a minute to heat the plate in the weld area. It will be seen that the entire mass of both helium and argon is heated to a higher temperature and has a much greater tendency to rise. However, both gases still reveal adequate coverage.

A decreased arc current which results in the addition of less thermal energy to the gas streams, Fig. 4 (*e*) and (*f*), does not create as large an expansion of the argon gas which does rise. The effect in the reduction of current on helium is negligible.

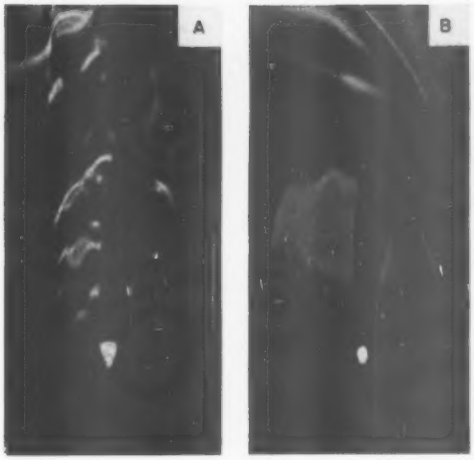


*Fig. 5 Influence of arc on unobstructed gas flow, 10 cfh. gas flow, 50-amp. arc current, 3/32-in. diameter nozzle*

An increase in nozzle diameter with a consequent decreased velocity at the basic 10 cfh. gas flow, Fig. 4 (*g*) and (*h*), also induces less turbulence. However, in a quiescent atmosphere, satisfactory shielding results. This decreased turbulence is due to the reduction of the Reynolds number.

The effects of the arc on the flow patterns of helium and argon without the gas impinging on the workpiece are shown in Fig. 5. Because of the greater thermal conductivity and heat capacity of helium, the stream expands to a much larger diameter in the immediate region of the arc. In addition, these illustrations show how argon breaks up into tubulence much closer to the nozzle exist as explained by its higher density-viscosity ratio. It should be pointed out that whenever turbulence is present at a gas boundary, entrainment of air will result.

## CONCLUSION

Analysis of gas coverage by the Schlieren method in still air has shown that many variables must be considered so that erroneous conclusions drawn from a single set of conditions may be avoided. Contrary to the assumptions made by others, argon, even though ten times as heavy as helium at room temperature, does not give more complete protection at the same rates of flow. The present study makes it clear that the selection of either helium or argon as the shielding gas should not be grounded upon the fluid dynamic properties of the gases. The gas should be selected on the basis of its electrical properties and economics for the particular application involved.

# Resistance and Fusion Welding of Titanium and Its Alloys

***Some Preliminary data on properties of titanium and its alloys, and techniques for spot, flash and inert arc welding of titanium***

*by E. F. Holt and W. H. Moore*

## INTRODUCTION

TITANIUM metal, which only recently has been made available commercially, is the fourth most abundant structural element in the earth's crust. It promises to be one of the important structural metals of the future. Present and proposed uses of titanium and titanium alloys are nearly unlimited.

Titanium presently is being considered as a replacement material for alloy and stainless steels. This is so because it has a higher strength-weight ratio than either of these two materials. Its futute application will depend on this favorable characteristic, as well as its corrosion resistance, and excellent properties at temperatures up to 1000° F.

Due to its newness, the cost of titanium and titanium alloys is comparatively high, but it is indicated that constant price reductions will be made as production increases and technological advances are made.

Some important mechanical and physical properties of titanium and titanium alloys are given in Table 1. The alloy designations are those of The Mallory-Sharon Titanium Corp.; these alloys, as well as other alloys having intermediate strengths, are available in pilot plant quantities.

It is quite natural to ask, can this new metal be machined, formed or welded as is steel, aluminum and other

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**Table 1—Properties of Titanium, Titanium Alloys and Other Structural Alloys**

| PROPERTY—MATERIAL | (1) Mallory-Sharon C. P. Titanium L-2830 Less Than 0.25% C. | (2) Mallory-Sharon Titanium Alloy L-2749 0.4%-0.7% C. | (3) Mallory-Sharon Titanium-Alloy L-2748 3%Al, 5%Cr, 0.4%-0.7%C. | (4) Steel Cold Rolled SAE 1010 | (5) Steel Stainless Type 302 | (6) Aluminum 24 ST Alloy |
|---|---|---|---|---|---|---|
| Ultimate Tensile Strength (P.S.I.) | 75,000 | 90,000-105,000 | 165,000 | 55,000 | 90,000 | 70,000 |
| Proportional Limit (P.S.I.) | 38,000 | 65,000-75,000 | | | | |
| Yield Strength (0.2% Offset) (P.S.I.) | 50,000 | 80,000-95,000 | 153,000 | 25,000 | 35,000 | 41,000 |
| Elongation (% in 2 inches) | 20-30 | 15-20 | 10 | 20 | 50 | 15 |
| Reduction in Area (%) | 45-70 | 35-50 | | 45 | 65 | |
| Elastic Modulus (x10⁶) (P.S.I.) | 15-17 | 16-18 | 18 | 30 | 24 | 10 |
| Hardness Rockwell "A" | 60 | 62 | 71 | 44 | 50 | 45 |
| Density (Lbs./Cu. Inch) | 0.16 | 0.16 | 0.16 | 0.28 | 0.29 | 0.10 |
| Electrical Resistivity (Microhm.—Cm.) | 54 | 60 | 140 | 10 | 73 | 6 |
| Electrical Conductivity (% I. A. C. S.) | 3.2 | 2.9 | | 15 | 3 | 30 |
| Thermal Conductivity (B.T.U./ft.²/in/°F./hr.) | 92-118 | 92-118 | 92-118 | 300 | 178 | 118 |
| Coefficient of Linear Expansion (in./in./°C.) | $8.5 \times 10^{-6}$ | $10.4 \times 10^{-6}$ | $0.9 \times 10^{-6}$ | $13.5 \times 10^{-6}$ | $18.0 \times 10^{-6}$ | $23.2 \times 10^{-6}$ |
| Specific Heat (B.T.U./lb.°/F.) | | 0.129 | | .21 | 0.21 | .41 |
| Melting Point (°F.) | 3135 | 3135 | 3135 | 2800 | 2550 | 1300 |

(1) Properties are for annealed sheet.
(2) Properties are for annealed sheet.
(3) Properties are for forgings.
(4) Properties are for forgings.
(5) Properties are for forgings.
(6) Properties are for forgings.

metals? These questions, of course, have not as yet been completely answered, but with more and more titanium becoming available, much knowledge is forthcoming.

Titanium has been welded successfully by several of the common welding techniques. Among them are resistance, spot and flash welding, and inert-gas-shielded-arc welding.

## RESISTANCE SPOT WELDING

Indications are that spot welding and seam welding will produce welds which are free from inclusions and superior in strength and ductility to those made by other methods of welding titanium.

The properties of low electrical and thermal conductivity of titanium and its alloys coupled with low coefficient of thermal expansion are conducive to ease of spot welding. It appears that sound welds may be obtained over a rather wide range of welding machine settings. In general the best spot welds are obtained using shorter weld times and higher currents.

Spot weld strength and consistency appear not to be greatly affected by the oxide coating which forms on the titanium sheet at room temperatures so long as hot formed scale has been removed. Heavy scale is best removed by first sandblasting followed by sodium hydride cleaning and finishing with a bright dip in a 2% hydrofluoric–10% nitric, balance water, solution.

Excessive penetration appears to be a characteristic of spot welds in titanium and titanium alloys. Welding conditions must be selected to limit the penetration to a reasonable amount. The weld nugget metal seems to be quite brittle which makes excessive penetration serious, since normal tension strength would be low.

Penetration and weld size are best determined by sectioning a weld, polishing and etching with 5% hydrofluoric acid etchant.

The weld shear strength (tension-shear specimens) seems to be high, although there is a tendency to low normal tension strength (cross-tension specimen) indicating lowered ductility of the weld zone.

The literature states that the ductility of the weld metal decreases as the carbon content of the material increases and conversely.

At present specific information on spot welding conditions is meager due to the limited amount of research which has been conducted.

Limited spot welding tests conducted in the P. R. Mallory Welding Laboratory on 0.4% carbon titanium sheet resulted in the welds shown in Fig. 1 which were made under the conditions given in Table 2.

**Table 2—Conditions for Welds Shown in Fig. 1**

| | |
|---|---|
| Welder | 100 KVA Press Type—Single Phase, A.C.—Motor Operated |
| Control | Synchronous Ignitron |
| Electrode Material | Mallory 3 Metal |
| Electrode Design (both electrodes) | No. 2 Morse Taper, Fluted electrode, Radius face. (see below) |
| Material Welded | 0.40% Carbon titanium |
| Material Thickness | 0.060" |
| Material Finish | Cold rolled, clean |
| Material Preparation | Degreased in carbon tetrachloride |

| Sample No. | Weld Time (cycles) | Weld Force (lbs.) | Welding Current Approx. (Amps.) | Electrode Face Radius (in.) | Mallory Electrode Code Number |
|---|---|---|---|---|---|
| 1 | 10 | 1000 | 8000 | 3 | F-3825 |
| 2 | 10 | 1000 | 9000 | 3 | F-3825 |
| 3 | 10 | 1000 | 10,000 | 3 | F-3825 |
| 4 | 8 | 1000 | 8000 | 3 | F-3825 |
| 5 | 8 | 1000 | 8000 | 10 | F-3625 |
| 6 | 8 | 1000 | 7500 | 10 | F-3625 |

*Fig. 1. Photomicrograph of titanium. Weld sections. Etchant, 5% hydrofluoric acid. Metallographic sample No. 7116. (Dots are hardness impression positions—see Table 4.) Magnification 5 ×*

Table 3 lists properties of the welds shown in Fig. 1.

**Table 3—Properties of Welds Shown in Fig. 1**

| Weld Number | Tension-Shear Strength (lbs./weld) | Slug Pulled | Weld Dia. (in.) | Heat Zone Dia. (in.) | % Weld Penetration | % Heat Zone Penetration |
|---|---|---|---|---|---|---|
| 1 | 2700 | yes | 0.266 | 0.290 | 77 | 93 |
| 2 | 2900 | yes | 0.285 | 0.300 | 82 | 90 |
| 3 | 3400 | yes | 0.310 | 0.335 | 90 | 95 |
| 4 | ..... | ..... | 0.221 | 0.265 | 76 | 93 |
| 5 | ..... | ..... | 0.175 | 0.234 | 72 | 93 |
| 6 | 2600 | no | 0.110 | 0.220 | 59 | 90 |

In the test, electrode indentation was slight and no sticking of electrodes was encountered. Spot welds were characterized by absence of porosity and negligible shrinkage. All welds of suitable size possessed columnar structures. Most suitable conditions developed were those for Weld 2. The electrical and thermal conductivity of titanium is comparatively low and it is probable that a harder (with somewhat lower conductivity) electrode material may be used with attendant lower rate of electrode deterioration. For example, Mallory 100 electrode material may provide longer electrode life than the Mallory 3 Metal.

The results of microhardness survey on the welds shown in Fig. 1 are compiled in Table 4. While hardening of the weld area is evidenced by the hardness survey, the amount of hardening is not too pronounced. It seems indicated that the lowered ductility of the weld metal was not primarily the result of increase in hardness.

**Table 4—Microhardness Survey Through Welds on 0.4% Carbon Titanium**

VICKERS HARDNESS NUMBERS

| | Impression Position* | | | | |
|---|---|---|---|---|---|
| | In Parent Metal | In Weld Area | | | In Parent Metal |
| Weld Number | 1 | 2 | 3 | 4 | 5 |
| 1 | 236 | 267 | 282 | 270 | 148 |
| 2 | 232 | 254 | 258 | 254 | 185 |
| 3 | 220 | 254 | 254 | 256 | 202 |
| 4 | 222 | 242 | 236 | 254 | 185 |
| 5 | 192 | 240 | 254 | 256 | 232 |
| 6 | 213 | 270 | 246 | 272 | 247 |

*Impression positions are from right to left shown in Fig. 1.

## FLASH WELDING

Only a very limited amount of work has been done on flash welding titanium; however, at least one manufacturer is flash welding titanium rings used on jet aircraft engines. In this case $^1/_2$-in. round rods of titanium were flash welded, producing a tensile strength of 115,000 psi., the fractures occurring in the parent metal. Bar stock 1 x $1^1/_4$-in. is flash welded on a 750 kva. machine with a $^3/_4$-in. burn-off and $^3/_4$-in. upset in a 15-sec. cycle.

Some literature indicates that flash welding is accomplished best in an argon chamber or by directing several argon jets (toward the weld zone) from a perforated tube. The former method of shielding is more complete. Strong, sound welds are obtained. Shielded welds are apparently more ductile than nonshielded.

Die burns must be avoided in flash welding. Dies must fit the work very closely; otherwise, small die burns cause points of stress concentration where fracture is likely to start.

Electrode materials for the welding dies must have a reasonably high electrical and thermal conductivity and a degree of malleability if the part to be welded is of irregular shape. Mallory 3 and Mallory 53B Metal is recommended in the wrought (forged) condition, except for irregularly shaped dies where castings may be much more economical.

Titanium pieces, 3/16 x 3 in., have been jointed by flash welding using copper alloy dies and the following machine settings.

| | |
|---|---|
| Die spacing: | |
| Initial, in. | 7/8 |
| Final, in. | 5/16 |
| Flash-off, in. | 5/8 |
| Upset, in. | 5/16 |
| Current cutoff, cycles | 5 |
| Flash time, sec | 4 |
| Arc voltage, v. | 5.6 |
| Maximum secondary current, amp. | 25,000 |
| Static upset force, lb. | 6,000 |
| Work overhang in dies | Equal |

## INERT-GAS-SHIELDED-ARC WELDING

Shielded arc welding may be readily accomplished using standard inert-gas-shielded-arc welding equipment with a preference for argon as the shielding gas. Considerable brittleness appears characteristic of the welds although the tensile strength is high. Weld area tensile strength has been found to be as high as 93% of the parent metal strength. Ductility in the weld and weld area tends to decrease as the carbon content increases; therefore, best weld results have been obtained using titanium with carbon content less than about 0.25%. At the present time titanium with this low carbon content must be made by the arc melting process.

Welds may be heat treated to restore or improve ductility, but as yet the optimum treatment has not been established.

During welding, air should be excluded from the underside of the weld as well as from the topside. This can best be accomplished by either a close fitting back-up plate, or by shielding the back with inert gas. The back-up plate when used should be of high thermal conductivity material such as Mallory 3 Metal.

Best welds have resulted from using direct current-straight polarity. Most welds have been made without the use of filler rods, allowing the two parts to flow together; however, some filler rod has been made by shearing 1/8-in. wide strips from 1/8-in. sheet. It is generally agreed that mill scale should be removed prior to welding, but there is disagreement regarding removal, immediately prior to welding, of oxides formed at room temperature.

In several cases, there was noted a black and sometimes yellow powder deposit adjacent to the weld area. It is suspected that these deposits may be oxides caused by incomplete shielding of the arc or impurities in the shielding gas, or they may be compounds of condensed titanium vapor.

Typical shielded-arc welding conditions are those used on 1/8-in. forged and rolled plate of an alloy. They are:

| | |
|---|---|
| Type weld | Butt |
| Current, amp. | (Direct current-straight polarity) 85 |
| Arc voltage, v. | 15 |
| Shielding gas | Argon |
| Gas flow, liters per minute | 6.2 |
| Underside gas flow, liters per minute | 10.6 |

For ease of starting and improved arc stability Thoriated Tungsten Electrodes are recommended.

## SUMMARY

The welding conditions given here are in no way meant to be optimum conditions, but only a guide by which other conditions may be judged. At present, considerable work is being done on welding titanium.

## ACKNOWLEDGMENT

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# Oxygen Cutting of Defense Equipment Materials

***Alloy steels sometimes require special precautions in oxygen cutting in order to avoid adverse metallurgical effects***

*by A. H. Yoch*

OXYGEN cutting of rolled alloy steel plates, forgings and castings on a production basis presents numerous problems which require careful study and the setting up of procedures or standards of control in order to secure the most satisfactory results.

The standard oxygen and machine cutting equipment, procedures and control are used as a basis to start. When alloy steels are cut, however, consideration must be given to the metallurgical effects of oxygen cutting and additional precautions taken to enable us to produce a finished product which has all of the properties desired for the given alloy.

To secure the desired metallurgical results, production quantities and specified cutting tolerances when working on a mass production basis it is essential to have very close cooperation and understanding between the metallurgical and shop production divisions.

The following description of the oxygen gas cutting process, illustrated by photographs of actual applications, is designed to be of assistance in the development of specifications and procedure control for the proper, economical and accurate cutting of various kinds of steel used for defense equipment materials.

## GAS CUTTING PROCESS

The oxygen gas cutting process is primarily a chemical action based on the chemical affinity of oxygen for ferrous metals, when raised to, or above, the kindling temperature.

In addition to the chemical reaction in oxy-gas cutting, there is a mechanical eroding effect produced by the oxygen cutting stream, which washes away considerable molten metal in metallic or unoxidized form.

The preheating flames, using oxygen mixed with acetylene, hydrogen, natural gas, propane or any other low-temperature fuel gas, are used to bring the edge of the steel up to the kindling temperature or 1400 to 1600° F. When this temperature is reached a stream of pure oxygen under pressure is directed upon the heated metal, producing a severing cut or narrow slot called the kerf.

The cutting torch or torches may be operated by hand or by machines for shape cutting and beveling of the edges for welding. Machine gas cutting produces the most satisfactory results.

## FUNDAMENTAL REQUIREMENTS

It is necessary to be definite when referring to the "quality of the cut." A satisfactory commercial cut may be defined as one fulfilling the following requirements:

(*a*) A sufficiently short drag; that is, the line markings on the face of the cut should be nearly vertical through most of their length rather than dragging back so far that the bottom edge is not cleanly cut and must be broken off to obtain severance.

(*b*) Sufficiently smooth sides of cut; i.e., not grooved, fluted or ragged.

(*c*) Satisfactory slag condition. For most production work there should be no firmly adhering slag that involves an appreciable expenditure of labor for its removal.

(*d*) The upper edges of the cut should be sufficiently sharp for the requirements of the particular job, not melted or rounded over.

The first two features just mentioned, viz., length of drag and smoothness of cut, are generally of greater practical importance than the other two, and of these two the length of drag is of greater fundamental importance. In fact, if one begins by considering only the length of drag as a basis for deriving the most economical cutting conditions it will be found that, in general, these conditions are not inconsistent with the requirements for a sufficiently smooth cut, satisfactory slag condition and sharp edges.

The most important independent variables are as follows:

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1. Size of the cutting orifice.
2. Oxygen cutting pressure.
3. Speed of cutting.
4. Thickness of the material being cut.
5. Analysis of the steel being cut.
6. Quality of the material.
7. Purity of the oxygen.
8. Intensity of the preheat.
9. Angle of incidence of the cutting stream to the upper edge.
10. Smoothness of cutting gas orifice and preheat orifices.
11. Cleanliness of the end of the torch tip. This influences the shape of the preheat flames and cutting stream.

The rate of oxygen consumption is dependent upon the first three of these variables and is not a separate independent variable.

For any given cut each of the variables listed should be so evaluated that the precise quality of cut desired may be realized with the minimum aggregate cost in oxygen, fuel gas, labor and overhead.

## BASIC CUTTING PROCEDURE

Because of extreme variations in such factors as the quality of the steel, cleanliness of the tip and the skill of the operator, as well as in the acceptable standards of production, it is not possible to establish a universally dependable table of cutting pressures, tip sizes and speeds. Cutting tables must not be looked upon as cutting "specifications" but rather as approximate cutting "guides" which are sufficiently appropriate under average conditions to enable trial cuts to be made with a fair probability of success. Because cutting tables are but preliminary and approximate guides it is only natural that different manufacturers of cutting equipment supply somewhat different tables of cutting data.

Following the inspection of the trial cut, more practical working conditions for the particular job may be evolved by carefully and appropriately modifying the speed of cutting, tip size and the operating pressures.

After an operator has acquired sufficient experience with the particular thickness and quality of steel involved, he may depart rather widely from the conditions specified, particularly in the direction of lower operating pressures and higher speeds, provided he does so cautiously and with due recognition of the fact that one or two successful cuts at greatly reduced pressures or increased speeds do not justify standardizing upon the revised practice. Under any circumstances, haphazard cut-and-try methods are to be condemned.

It is particularly important to observe that frequently there is a pressure or speed which proves exactly right, and that an increase or a decrease of more than one or two pounds will lead to markedly inferior cutting results.

In general, the cutting conditions listed in cutting "guides" or charts are very conservative. As a rule, experience with the given steel and methodical evolution of more specifically applicable cutting conditions will result in greatly decreasing the cutting costs. Particularly with certain alloy steels, the cutting conditions specified in the table will often be inadequate.

Nevertheless, whatever the cutting conditions employed for any given cut and whatever the nature of the steel which is being cut, the procedure which should be followed toward improving the operation during subsequent cuts is much the same. It should be understood in this respect that the evolution of the most satisfactory cutting conditions for any given thickness, analysis and quality of steel, to produce cuts corresponding to specific standards of appearance, is a process which calls for intelligence, experience and skill if the optimum performance is to be realized.

The details of the process may be varied somewhat according to the preference of the operator, but they should by all means be systematic and in accordance with principles outlined previously.

If a cut fails to propagate continuously, and if the failure is obviously a failure originating at the upper surface of the steel, the fault may be that the surface condition of the steel is not satisfactory for continuously propagating the cut with the given preheat intensity.

When the steel is clean and free from rust, heavy scale or paint, exceedingly light preheat will ordinarily be adequate, but even with such a steel it occasionally occurs that the cut will be interrupted as the result of some slight slag defect at the surface of the steel. Such defects are not always obvious upon superficial examination; therefore, close inspection of surface condition should always be made before cutting.

## APPROXIMATE GUIDE FOR MACHINE GAS CUTTING OF ALLOY STEEL

The charts or data for machine cutting supplied by the various manufacturers of cutting equipment are based upon cutting of low-carbon steel. For cutting of higher carbon or alloy steels the usual procedure is to make trial cuts using the standard charts for low-carbon steel as the basis for these initial cuts.

The general procedure is to use the tip sizes and pressures specified, but to start with lower speeds, and gradually raise the speeds. Frequently alloy steels can be cut with practically the same tip size, speed and pressure as that specified for low-carbon steel.

Because the standard charts are as a rule conservative, experienced operators can often use higher speeds or lower pressure than those specified.

Table 1 is an example of an approximate guide for machine gas cutting of alloy steel plates. This was developed for use by a concern which was confronted with the necessity of starting from scratch.

An example of interest is that this approximate guide was used for the training of a crew of inexperi-

**Table 1—Approximate Guide for Training Operators to Oxygen Machine Cut Rolled Alloy Steel Plate Using Oxyacetylene**

| Depth of cut, in. | Tip size No. | Drill size No. | 90 degree cut: Oxy. pressure | 90 degree cut: Acet. pressure | 90 degree cut: Speed, in./min. | 0 to 30 degree angles: Oxy. pressure | 0 to 30 degree angles: Acet. pressure | 0 to 30 degree angles: Speed, in./min. | 30 to 45 degree angles: Oxy. pressure | 30 to 45 degree angles: Acet. pressure | 30 to 45 degree angles: Speed, in./min. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3/8–3/4 | 2 | 55 | 30 | 5 | 12 | 30 | 5 | 10 | 30 | 5 | 8 |
| 3/4–1 1/4 | 3 | 53 | 38 | 5 | 9 | 38 | 5 | 8 | 38 | 5 | 7 |
| 1 1/4–2 | 4 | 50 | 45 | 5 | 8 | 45 | 5 | 7 | 45 | 5 | 6 |
| 2–3 | 5 | 47 | 50 | 5 | 7 | 50 | 5 | 6 | 50 | 5 | 5 |

*Note:* The above chart was used as a basis for the training of inexperienced female operators for production cutting. After operators acquired sufficient knowledge and skill, cutting speeds and pressures were gradually increased. With proper training the cutting speeds, etc., recommended in the standard (low-carbon) charts were approached. All cutting was done with oxyacetylene at shop temperature 60–70° F.

enced operators for production cutting. Over 85% of this operating crew were women.

Spoilage was held to a minimum, and in the course of six months cutting speeds were increased by approximately two to three inches over those specified in the chart.

After this six-month training period, the average performance was as follows. Using shape cutting machines on 90-degree cuts, the speeds were increased as follows:

Cutting steel up to 1 in. thick—from 12 to 13 in. per minute.

Cutting steel up to 1 1/2 in. thick—from 8–9 in. to 11 in. per minute.

Cutting steel up to 2 in. thick—from 7–8 in. to 9–10 in. per minute.

Using Radiagraph straight line machines on bevel cuts of 30 to 45 degrees, speeds were increased as follows:

Cutting steel 3/4 to 1 1/2 in. thick—from 8 to 11 in. per minute.

Cutting steel 1 1/4 to 2 in. thick—from 6 to 9 in. per minute.

Some operators acquire knowledge and skill quite readily and they can then modify the speeds and pressures or other operating techniques to suit their abilities without danger of spoilage to hindering production.

The foregoing example indicates the kind of procedure control used in production cutting regardless of what alloy metal is cut.

Proper supervision is required and with a given standard for a quality cut it is necessary to permit a reasonable variation of tip sizes, pressures and speed in order that the supervision responsible for control can do production work with the personnel available.

With a control of this kind, experience shows that after proper training, operators can do good cutting without sacrifice in quality or economy of gases and time and can approach the figures used in the manufacturer's standard cutting charts.

## CUTTING TIPS

The general procedure recommended for alloy steel cutting is to use a cutting tip which is one size larger than that recommended for low-carbon steel, using lower oxygen cutting pressures. The lower cutting oxygen velocities seem to work out most satisfactorily, particularly where segregations are encountered.

The high velocity (divergent) type of cutting tip has also been used with entire satisfaction. The general procedure with this type of tip is to use somewhat reduced speeds.

## FUEL GASES

The quench action and hardening effect of gas cutting on alloy steel plate does not appear to be altered by the use of different fuel gases. Acetylene is recommended because its use permits cutting to be done at higher rates of speed.

Hydrogen, natural gas, propane, city gas, etc., can be used with suitable tips, and will produce good results. Cutting speeds are approximately 10% slower with these gases.

Some difficulty is encountered on the cutting of bevels because of the low heating value of low temperature gases. Moreover, care must be exercised to avoid gouging, which should be avoided because it offers a starting point for checks, and is also objectionable for welding.

## QUALITY OF GAS CUTTING AND QUALITY INDICATORS

It sometimes happens that a given combination of cutting variables will not always give rise to a definite length of drag. Usually, however, the variations in drag length are restricted within fairly definite limits. These variations from the normal length of drag are often traceable to variations in the quality of the material being cut. Apparently, nonhomogeneity of the physical structure of the steel is an important consideration.

With good quality steel the following results have been obtained. These serve as indicators to correct cutting practices.

### *Guides to Proper Cutting Technique*

*With the correct pressures, speeds and tip sizes* the cut surfaces are plane and regular, and the drag lines are practically perpendicular. The slight amount of scale remaining at the top of the preheated surface and on the face of the cut can be easily scraped off. The

surfaces are excellent and for many purposes serve equally as well as machined surfaces.

*Cutting speed too low:* Will cause undercutting or ripping of lower portion of the cut faces, resulting in very irregular surfaces of notched effect on lower faces of cut.

*Cutting speeds too high:* Will result in excessive drag. If the surface is reasonably smooth and the cuts are to be made perpendicular this type of cut may be acceptable for production rip cuts on straight lines. Excessive drag makes it impossible to use high speeds for shape cutting because of danger of deviation from a perpendicular plane. Excessively high speeds result in loss of cut.

*Oxygen cutting pressures too high:* When excessive oxygen cutting pressures are used the cut surfaces are sometimes distorted by excessive expansion of the cutting stream below the surface of the cut, causing horizontal flutes. Where inclusion or other defects are encountered, gouging is apt to occur.

*Oxygen cutting pressures too low:* If cutting oxygen pressures are too low the cut will fail to penetrate completely. Reduction in cutting speeds usually corrects this condition and makes possible a thorough cut.

*Preheat too high*: Excessive preheat is an unnecessary waste of gases. The use of excess preheat does not affect the cutting speed, but merely melts over the top edges of the metal.

*Preheat too low:* Insufficient preheat results in loss of the cut because the steel is not brought to kindling temperature rapidly enough. Scale, pits or imperfections on the surface of the steel also cause loss of cut when preheat is adjusted too low.

*Cutting tip too far from work:* When cutting at normal speeds the end of the visible inner cone of the oxyacetylene preheat flames should be slightly above the plate surface. When natural gas, propane or other low temperature gases are used for preheating, the practice is to adjust the fuel gas pressure to give a flame about $^1/_2$ in. long, and then adjust the preheat oxygen to produce a sharp flame approximately $^5/_{16}$ in. long. The final adjustment is made to a point where a high pitched sound is heard. The flame position should be such that the pin points of the flame are slightly above the plate surface.

*Cutting tip too near the work:* With the cutting tip positioned too near the work the preheat flames will not be in a correct position to take advantage of proper preheat, and cutting speeds will be reduced. Further, a portion of the preheat cone burns inside the kerf, resulting in an unstable condition and causing defects in the cut surface such as grooves or exaggerated drag lines.

Tips operated too close to the work are apt to be fouled easily, resulting in bad cuts.

*Dirty tips:* Tips that have been damaged by adhering slag or scale will result in the oxygen stream losing its parallel form and the cut surfaces will no longer have a plane, true face. Orifices of cutting tips damaged in any manner should be cleaned and trued up with proper cleaner drill or rods.

The following is a list of the most important conditions which should be maintained in the interest of smooth cuts:

1. Uniformity of torch movement.
2. Uniformity of oxygen regulation. (Important for heavy thicknesses and cold weather cutting.)
3. Uniformity of steel being cut.
4. Smoothness of bore and proper type of cutting orifice.
5. Cleanliness of orifice exit.
6. Sufficiently high oxygen—purity—99.5% is desirable as commercial standard.
7. Correct oxygen cutting pressure.
8. Correct preheat flames—volume and pressure.
9. Proper operating speeds for the tip size and oxygen pressure used.

## METALLURGICAL EFFECTS OF OXYGEN CUTTING

A considerable quantity of heat is liberated in the kerf when steel is cut with the oxygen jet. Much of this heat is tranferred to the walls of the kerf and as a result the metal for an appreciable depth adjoining the cut surface is heated rapidly to a temperature well above the critical range.

As the cut progresses and the source of heat moves on, the mass of the cold metal near the cut acts as a quenching medium and rapidly cools the heated metal. The phenomenon is in some respects similar to that of the usual heat-treating operation.

A piece of steel, heated to above the critical temperature range and rapidly cooled, will naturally harden. The degree of hardening will depend to a large extent on the amount of carbon and alloying elements present in the steel, and also on the rate of cooling.

Such a hardening reaction occurs at the face of the cut where the temperature of the cutting operation has been sufficiently high to raise the metal well above the upper critical or A3 transformation temperature, and where this zone is bounded by large masses of relatively cold metal.

During the process of flame cutting, an upsetting action takes place on the face of the cut; upon cooling, contraction takes place and the cut edges become stressed. When stresses exceed the elastic limit of the steel, checks are apt to develop. While it is known that checks or microscopic fissures develop in cut surfaces of certain steels, there is some question as to whether this detrimental effect occurs after the flame cut is made and during the quench action or over an extended period of two or three hours.

Flame softening of the cut edges is required only when the plate is to be formed, shaped or highly stressed or machined.

The elimination of nickel and chrome and the use of other elements to provide hardenability and strength

will undoubtedly have an influence upon the behavior of the metal under the cutting reaction. It should be recognized that as the carbon, manganese or silicon content is increased the possibility of checks increases.

Steels containing as much as 0.30 or 0.35 carbon are cut, without preheating or postheating. This group includes low- and medium-carbon nickel steels; low nickel-chromium, low nickel-molybdenum and low chrome-vanadium steels of low-carbon content; aluminum and copper-bearing steels; and low tungsten alloys.

In order to make a determination of the effects of flame cutting, it is necessary to conduct a metallographic examination of sections of steel of a known analysis, flame cut under controlled conditions.

## HEAT TREATMENT

The recommendation generally made for heat treatment is that steel of over 0.30 carbon content should be preheated between 200 to 1100° F., depending upon alloy content. The cut sections should then be returned to the furnace and annealed at the proper temperature for the particular grade of steel involved. In practice the lowest possible temperature is used when preheat is required to avoid checking.

Preheating accomplishes several useful purposes:

(*a*) Preheating increases the efficiency of the flame cutting operation by reducing the amount of oxygen required to make the cut.

(*b*) It reduces the temperature differential between the cutting reaction and the adjacent body of metal. This in turn reduces or gives more favorable distribution to the cooling stresses and, thereby, prevents the formation of quenching or cooling cracks.

(*c*) It minimizes hardening of the cut surface by reducing the rate of cooling.

(*d*) It reduces the carbon and nickel migration toward the cut face by lowering the temperature differential.

The proper temperature should be determined by a metallurgical check on cut specimens to ascertain the lowest temperature at which cuts can be made without injury to the steel. The higher-alloy steels which are cut hot are: high-carbon steels, almost irrespective of alloy content; manganese and silicon steels; high-carbon nickel steel; most nickel-chromium steels; medium-carbon molybdenum steels; chromium steels including the 4 to 6% type; chrome-vanadium steels of high-carbon content; and vanadium steels.

## GAS CUTTING ALLOY STEEL AT PREHEAT TEMPERATURES

Preheating may be carried out in a regular furnace and the pieces then moved to the cutting machines, or, if desired, suitable furnaces may be constructed on the cutting beds.

Despite the fact that preheating offers advantages, certain practical limitations are involved in its application, and care and judgment must be exercised when cutting at preheat temperatures.

Suitable precautions must be taken to protect the cutting machines against overheating, because of the possibility of failure of electrical equipment, bearings and machine slides.

Preheating also introduces difficulties in holding tolerances and shape of cuts. For this reason preheating is to be avoided wherever possible.

## GAS CUTTING ALLOY STEEL PRIOR TO FINAL HEAT TREATMENT

Experience shows that gas cutting of alloy steel prior to final heat treatment frequently results in cuts of poor quality. Pieces which are given final heat treating and tempering after cutting may become distorted, and may also expand in dimension or length by as much as $^{3}/_{16}$ to $^{5}/_{16}$ in. in 60 in. of length of $1^{1}/_{4}$-in. plates.

This "growth" or increase in size is not consistent over both dimensions. Cutting under these conditions can only be applied where edges are to be machined or otherwise processed after treatment.

## GAS CUTTING ALLOY STEEL AFTER FINAL TREATMENT

The greater portion of forged or rolled sections of the chrome nickel steels has been cut at room temperatures (60–70° F.) as a standard acceptable practice.

In a number of instances preheating to approximately 400° F. has been used. However, this practice has been employed only to a limited extent.

The sequence of operations employed by a number of Alloy Plate Fabricators is as follows:

1. Rolled slabs or plate are heated to the required temperatures and then water quenched.
2. Normalized at required temperature.
3. Flame cut at room temperature and left to air cool.
4. In some instances the flame cut pieces are removed to a furnace immediately and stress relieved at a temperature below the last drawing temperature. Held in furnace for 1 hr. and then air cooled.

*Note:* This does not constitute a complete working formula because the treatment temperatures to be used require a knowledge of the analysis of the steel and the physical characteristics required for a specific purpose.

## GAS CUTTING ALLOY STEEL AFTER FINAL TREATMENT AT ROOM TEMPERATURE (60–70° F.) AND ANNEALING OF CUT EDGES WITH FLAME SOFTENING PROCESS

Limitations of furnace capacity and lack of furnaces have brought about the development of methods and

procedures for local flame softening of the flame cut edges. The principle involved is to apply sufficient heat to the gas cut surfaces at a temperature below the last treatment temperature to effect a drawing or tempering action.

Numerous arrangements may be used, all of which are in all probability equally effective within a given scope:

1. Flame cutting and softening as a simultaneous operation, with the heat apparatus running either ahead of the cutting torch or behind it. In either case the heat is applied to the top side of the plate. A compromise of speeds must be developed for this procedure to allow time for heat penetration from the top surface of the cut plates. Experience indicates that the maximum plate thickness workable by this method is about one inch.

Fuel gases for flame softening may be acetylene or any of the low-temperature gases. Refer to Fig. 1, Practical Application.

2. Flame softening as a separate process, applied to the finished cut sections after all scrap and slag have been removed. Heating burners may be supplied by oxyacetylene or by such low-temperature mixtures as acetylene and air, or natural gas and air or oxygen.

Stationary burners may be used, or suitable burners and small furnaces may be attached to a portable Radiagraph® type of cutting machine for progressive flame softening of straight edges.

The portable type furnace (Genter Pat. No. 2,301,-864) has been used quite successfully for several years, employing low-temperature fuel gases and air or oxygen for flame softening of straight cuts and certain shaped cuts in thicknesses from $^3/_8$ to 12 in. (see Table 2)

**Table 2—Flame Softening of Alloy Steel Plate Using Natural Gas and Compressed Air**

| *Plate thickness, in.* | *Speed, in. per min.* |
|---|---|
| $^1/_2$–1 | 7 |
| $1^1/_2$ | 5 |
| 2 | 4 |

The equipment used consists of a portable Radiagraph type of cutting machine with adjustable arms to which is attached a portable furnace with a suitable burner for natural gas and compressed air, operating with 15 lb. pressure natural gas (1100 Btu.) and 95 lb. compressed air.

It is essential that the burner head be positioned approximately two inches from the rear opening of the furnace and that it be properly centered in relation to the furnace opening for the flame. The furnace opening should be centered in relation to the plate edges.

The burner should be lighted and brought up to a bright orange heat before operations are begun.

For operation on large sections of alloy steel plate the usual practice is to construct a work plate of sufficient size to permit the workpiece to be mounted on cylindrical pipe supports. The track for the machine can then be adjusted in proper relation to the edges to be softened and moved as required from point to point until all edges of the piece have been softened.

Trial runs are made to determine heat and speed adjustments required to obtain a given edge softness. From then on a standardized procedure can readily be established.

Actual practice has shown that for plate thicknesses up to and including 2 to 3 in. natural gas and compressed air is most satisfactory and economical. For thicknesses over three inches a ribbon type is required as a heating medium.

Some limited usage has been made of acetylene and oxygen on flame softening of heavy sections of alloy steel plates.

As a rule experience shows that the heat input should be such that temperatures are raised and lowered slowly to avoid a quench action and hardening.

## CONTROL OF CHECKING OR CRACKING OF ALLOY STEEL PLATES

(*a*) Preheating may be required. This can be best determined by a metallographic study of specimens flame cut and treated under various conditions. After determination of the behavior of these specimens the next step should be trial processing of the actual full size workpiece.

Practical observations and experience indicate that those types of steel which require a preheat for flame cutting also require similar treatment for welding.

(*b*) The quality of flame cut surfaces has a vital bearing upon the matter of checking. Gouging or ripping of the face tends to introduce a notch effect and should be avoided or held to a minimum. Grinding out of sharp notches to a radius is recommended to relieve stresses. In general sloppy workmanship in cutting is detrimental.

(*c*) Design of flame cut openings should be such that angular lines are joined by a corner having a generous radius. Sharp corners on inside openings have always been recognized as contributing factor to checking, either during the process of cutting or welding.

## FACTORS AFFECTING THE ACCURACY OF MACHINE GAS CUTTING

The importance of accuracy of machine gas cutting is very forcibly brought to our attention in view of our growing defense program.

The elimination of a machining operation for the fitting of parts or pieces for welding can be done provided we have close cooperation in the design and production divisions.

For example, we have many instances where a machined surface or ground surfaces are specified in micro

inches for a welding surface.

From a practical operating standpoint where we have a root gap of from $^1/_{16}$ to $^1/_4$ in. plus for a welded joint on thickness of $^1/_2$ to 4 in. the specification should call for a surface free from slag and where notching occurs due to segregations the surface shall be ground to remove the notch effect before welding.

The dimensions of the several pieces that are to be welded together is not difficult to maintain from a gas cutting standpoint when we take into consideration that on the welding of assembled pieces that we will have a root gap of from $^1/_{16}$ to $^1/_4$ in. plus.

In our estimation it then should follow that the engineering department and the production department should decide where the plus or minus dimensions are applicable.

Some work has been done to date on the matter of dimensional accuracy of gas-cut pieces. In 1922 a prominent manufacturer decided, as a result of a demonstration and extensive test of machine gas cutting of quadrant parts for a hydraulic lift mechanism, that they would replace all hand-forged or cast parts with machine gas-cut parts.

One of the problems encountered at the time was to hold a given dimension and eliminate machining.

The pieces were of an intricate shape and after much study and effort we found that regardless of the fact that an accurate template was used the pieces would vary depending upon the starting point of the cut and the sequence of the various cuts. The final solution was to measure the deviations developed in the cut piece at a given point and then alter the template dimension accordingly.

Another example of the demand for accurate cutting was the cutting of 33,000 pieces for segments of the Queens Midtown Tunnel.

This work started in November 1938 and was completed in May 1939 and required an accuracy of minus $^1/_{32}$ in. on pieces 1 in. thick, 10 in. wide and 5 ft. long.

The solution was to measure the dimensional change and then alter the cam to compensate for the shrinkage of the cut pieces. From December 1941 to June 1942 observations were made on the accuracy of cutting armor and these observations resulted in the development of specific information on dimensional changes during cutting of given pieces. Dimensional errors were found to vary with identical pieces due to improper support of the cut pieces.

After corrective measures were applied we found that in many instances the tolerances were held to plus or minus $^1/_{64}$ in. on pieces 2 ft. 6 in. by 4 ft. and on pieces 2 ft. 6 in. by 14 ft. plus or minus $^1/_{32}$ in.

As a result of the work of a group of three different gas manufacturers a meeting was held on Feb. 15, 1942, and a tolerance of plus or minus $^1/_{16}$ in. was agreed upon as satisfactory for the cutting of armor for the welded fabrication of army tanks.

To produce gas-cut pieces to meet a specific tolerance requires: machines that are accurate, proper set up and control of operations and the necessary personnel with the know-how engineering, supervision and production.

## PRACTICAL APPLICATION OF MACHINE CUTTING ALLOY STEEL PLATE SHAPES

Figure No. 1 shows a close-up view of a No. 4 Radiagraph cutting machine which is template guided to follow a given contour, with the cutting operation and flame softening operation done simultaneously at controlled progressive speeds. Definite pressures and speeds must be worked out for each given thickness and each given alloy. (U. S. Pat. No. 2,269,526—To J. F. Franzen.)

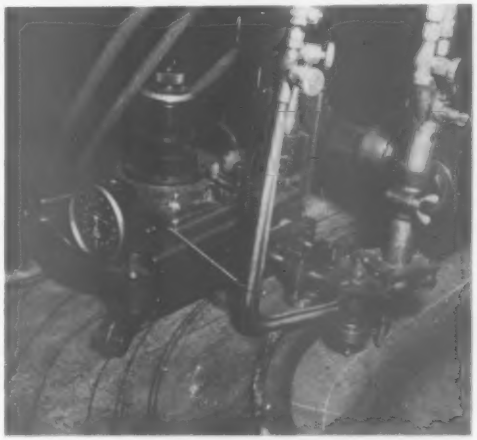

*Fig. 1 Simultaneous cutting and flame softening by post-heat, using a template and roller strip guide device for the machine and torches. J. F. Franzen, Pat. No. 2,269,526*

The machine gas cutting of alloy steel plate sections and shapes into "cookies" is usually done with the pantograph type of flame cutting machine. For the sake of speed and economy without a sacrifice of quality or accuracy of flame cuts the machines having a cutting range 10 to 12 ft. wide have been most satisfactory. The cutting beds with work support members for holding the plates can be made as long as desired thereby permitting finished cut work to be removed and new slabs laid down while cutting proceeds without interruption.

In order to secure accuracy in flame cut pieces the individual "cookies" are cut from rolled slabs of a width sufficient to provide a reasonable scrap allowance so that the entire contour may be cut to the required shape. In some instances nesting of cuts can be done in such a manner as to utilize a common severing cut to produce two adjacent finished faces. This practice serves to economize in time and material at no sacrifice in accuracy of cut.

Suitable templates and cutting techniques or procedures are necessary for all shape cutting, and once

these procedures and methods have been established as being correct, no difficulty is experienced in producing flame cut edges or shapes within the accuracy and tolerance established for welded fabrication.

To meet the requirements of the program for flame cutting of tank armor, gun carriages and other types of flame cut and welded fabrication, a special type of steel template was developed in order to permit making dimensional or shape changes quickly and economically.

Instead of cutting the entire template out of a plate, the new design comprises a sectional template made up of straight bars for straight cuts, joined by corner gussets or curved sections as required to complete the shape. These are joined and mounted upon a base plate with suitable fastenings of spacers and screws. This design permits alteration of any section for dimension or shape changes without any great cost or delay.

Photographs 2 and 3 show typical examples of such templates for use with magnetic tracers on the Travograph, and are sufficient for explanatory purposes.

Figure 2 shows a template used for multiple cutting of four irregular shaped pieces simultaneously. All edges were cut perpendicular on the Travograph and a secondary operation of cutting a welding bevel on the side having the semicircular notch was done in a jig using a Radiagraph.

Figure 3 shows a ball transfer device mounted on the underside corners of the template shown in Fig. 2. This ball transfer device permits rapid shifting of the entire template by the machine operator for locating it in proper relation to the workpiece. It eliminates much crane handling, saves time and permits one template to be accurately and quickly repositioned by sliding along a guide angle bar and clamping in position as shown in Fig. 4.

*Fig. 2 A built-up sectional type template for the magnetic tracer*

*Fig. 3 Under side of template shown in Fig. 2 showing ball transfer arrangement to permit quick shifting of entire template without crane service*

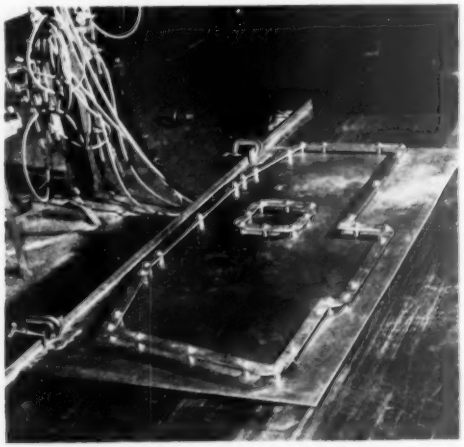

*Fig. 4 This view shows the general arrangement of a variety of sectional types of templates for magnetic tracers. This illustrates the ease with which the outline and locations of opening may be shifted to obtain a given accuracy*

The template shown in Fig. 4 illustrates quite clearly the use of separable sections joined to form a template that can be adjusted when required.

The general scheme of cutting out "cookie" shapes with the Travograph is to produce the shape with perpendicular edges or openings cut to size.

Where bevels are to be cut, sufficient stock should be left so that a template may be placed upon the work and aligned with certain edges or openings already flame cut to size, and then scribing a line for final cutting to size with the Radiagraph.

In some instances beveled edges occur on shapes in such a relation to one another that beveled edges and perpendicular edges may be cut on the Travograph in one continuous operation by adjustment of the torches at the proper angle in relation to the workpiece.

An example of this work is shown in Fig. 5 where four pieces are being cut simultaneously, with the two

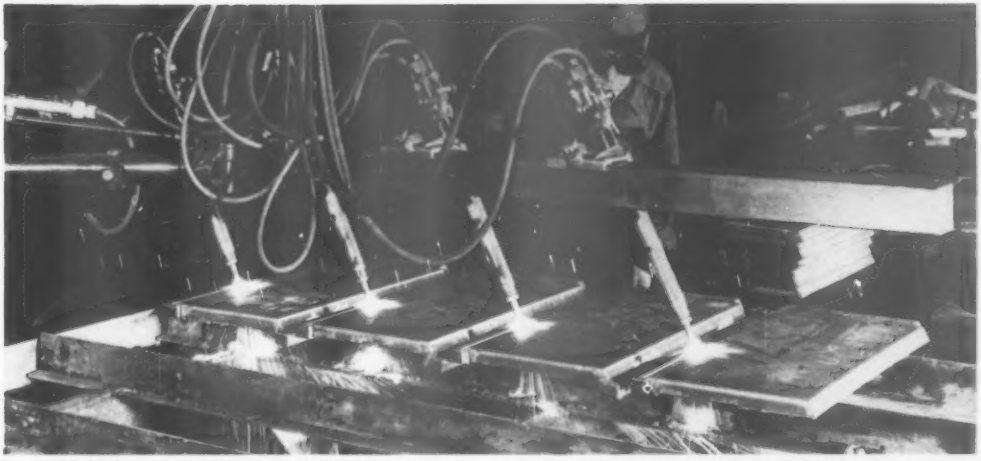

*Fig. 5 Multiple cutting of four pieces with two opposite sides at 20-degree angle and the two opposite ends at 90-degree angle using the magnetic tracer template*

opposite sides cut at approximately a 20-degree angle and the two opposite ends at a 90-degree angle, using the magnetic template.

Figure 6 is a photo of an oxyacetylene machine-cut gear which is an outstanding example of the accuracy obtainable by careful planning and procedure in oxygen cutting. The gear is 26 ft. in diameter, made up of 16 segments 5 ft. long. All segments were bolted to the frame by means of clips welded to each segment. No machine work or grinding was required to match the teeth. The steel was 1045—5 in. thick and was cut at shop temperatures and left to air cool.

Figure 7 is a close-up view of the accurate oxygen cutting of the thirteen tooth pinion gear for use with the 26-ft. diameter bull gear of a crane. This gear was 5 in. thick and made from 1045 steel. Experience developed on similar work in 1932 prompted the builder to make trial cuts and on the basis of their results all cutting was done at shop temperature and left to air cool.

No failures were encountered and an advantage gained was that the teeth were hardened with a result that better wear qualities were secured.

Figure 8 shows a special set up for the oxygen cutting of gear tires. A cylindrical forging of 7 in. thickness of 5 ft. width and 14 ft. O.D. is being sliced into two pieces. This cutting is done at preheat temperatures depending upon the alloy content of the steel. It is interesting to note that the track is approximately 20 in. thick and 18 ft. in diameter with a series of concentric grooves to guide the machine in a circular path around the ring forging.

Figure 9 shows the general arrangement of a No. 41 Travograph equipped for contour bevel cutting. At

*Fig. 6 A bull gear for 50-ton crane—26 ft. diameter—16 segments 5 ft. long. All segments bolted to framework by means of clips welded to each segment. No machine work or grinding required. Steel was 1045—5 in. thick cut at room temperature*

*Fig. 7 Close-up view showing accurate cutting of a 13-tooth pinion gear used with bull gear shown in Fig. 7. No machining of teeth required steel 5 in. thick—1045—cut at room temperature*

the right is the raised strip template for a manual guided tracer. The template tracer and the torch mechanism are interconnected by means of two pinions and a rack which transmits an identical motion to the torch with a special dual cutting tip. This tip cuts a slot $^1/_4$ x $^1/_2$ in. throughout the contour traced.

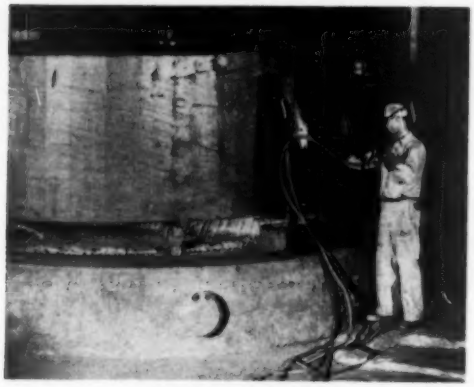

*Fig. 8 A special machine set up for cutting of forged gear tires—14 ft., diam.—7 in. thick into two pieces approximately 24 in. wide. The track was 20 in. thick—18 ft. diameter with concentric grooves machined in the face to guide the radiagraph around the forging*

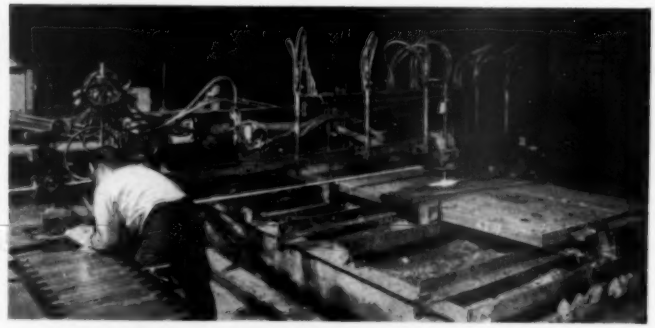

*Fig. 9 A view showing the general arrangement of a contour bevel cutting device mounted on a No. 41 Travograph. Using a manual guided tracer with a raised strip template as shown at the left. The rolled plate in position and being cut with the torch cutting mechanism at the right*

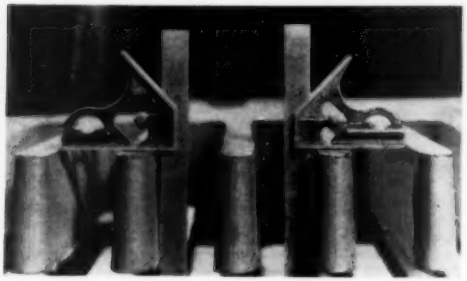

*Fig. 10 A close-up view of the cut pieces showing the accuracy of the taper match of the interlocking pieces which form an expansion joint which is self-cleaning*

Figure 10 is a close-up view of the cut pieces showing the accuracy of the taper bevel pieces and the uniform match of the taper interlocking pieces which form an expansion joint which is self cleaning.

This is an example of accurate oxygen machine cutting and it is particularly interesting because of the contour bevel shape cuts. Producing these two accurate matching members from one piece of steel could not have been accomplished by any other known method.

## NEW OXYGEN MACHINE CUTTING EQUIPMENT

The alertness of the metal working industry to the value and economy of the oxygen cutting process and the allied welding process of various types has resulted in the design and mass production of sturdier and more accurate equipment to meet the ever-growing needs of our industry.

Such developments are not the results of one individual person or one company. They are the results of many years of effort and experience and after a careful consideration of the immediate and future needs, a standard type of heavy duty machine was designed and produced that performs beyond expectations.

The new No. 50 Travograph (Fig. 11), an all-welded fabricated pantograph type cutting machine having a 12 ft. width and unlimited length of traverse: The machines weight with 8 torches and all auxiliary control and tracer unit is approximately 9500 lb. The standard tracer speeds are $1^1/_2$ to 28 in.—other speeds can be supplied and any one of four standard tracers can be supplied—viz., Spindle, Manual, Magnetic or Electronic. The carriage speeds are from 2 to 168 in. per

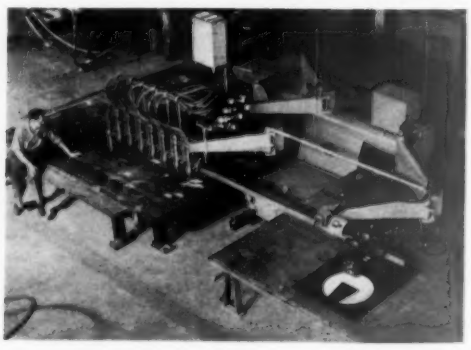

*Fig. 11 No. 50 Travograph—a pantograph-type oxygen cutting machine with a 12-ft. width range. Length range is unlimited. Four different types of tracers may be used. With a 500 lb. uniform loading a scribed circle 12 ft. in diameter shows no deviation*

minute forward or reverse and are controlled from the operator's position. With a uniform loading of 500 lb. a traced diagram of 12 ft. diameter shows no deviation from a true circle. The machine can be operated either right or left hand.

The carriage control box contains the remote electric speed control and also forward and reverse manual and automatic switch gear.

This enables the operator to have complete control of all speeds and all functions without moving from his operating position.

A remote switch control unit is shown at the left. This unit permits the individual selection of any gas for setting gas pressures and also the progressive control of all gases when ready to operate.

The gas distribution system assures an adequate supply of gases for cutting metal up to 6 in. thick with 8 torches. By decreasing the number of the torches in use, heavier thicknesses can be cut. Solenoid controlled diaphragm valves are used for oxygen cutting, oxygen preheat and fuel gases. Each manifold header is equipped with a gas pressure gauge and eight outlets for supplying the gases to 8 torches. The entire gas distribution assembly is suspended by means of a separate pantograph arm of its own to relieve the operating bar of excess load.

Figure 12 gives an illustration of the size of some templates used with the Electronic Tracer. Materials used were black Masonite Hardboard with the outline of what plastic tape superimposed on the Masonite. Such templates can be quickly constructed at a low cost as compared to metal templates. Should it be necessary to alter the shape of size this can be very readily done at a minimum of cost and time. This template is approximately 30 in. wide and 36 ft. long.

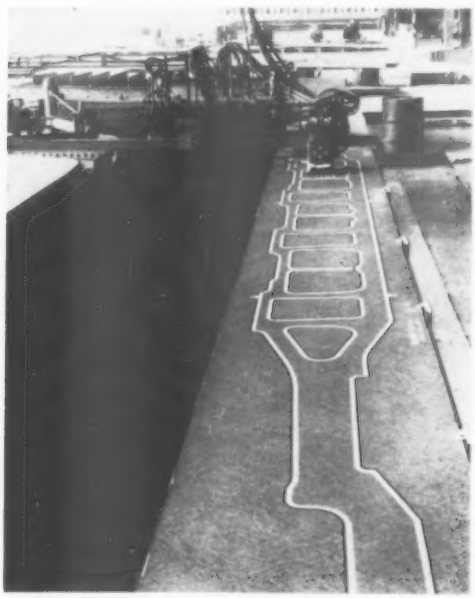

*Fig. 12 A template for the electronic tracer, using a black masonite board with white plastic tape superimposed which forms the outline to be traced. The size is approximately 30 in. width by 36 ft. long*

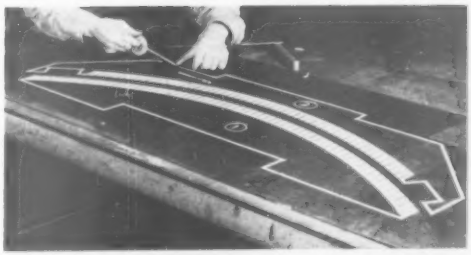

*Fig. 13 An illustration of the simplicity with which a very intricate template can be made at a minimum expenditure of time and money*

Figure 13 shows a layout of an Electronic Tracer template in the process of production for cutting a quench die.

It is interesting to note the numerous re-entrant sections, also the numerous narrow slots in both die sections. With this type of template using the Electronic Tracer, a continuous cut can be made without any difficulty or failure.

Other type templates would require numerous compound or attachment sections and would not permit of making a continuous progressive cut.

## SPECIAL HEAVY-DUTY CUTTING EQUIPMENT FOR THE REDUCTION OF HEAVY SCRAP TO CHARGING BOX SIZE

For a number of years the rapid and economical reduction of heavy scrap for remelting has been a serious problem for all steel mills. Numerous installations have been very profitable and satisfactory for a given specific mill requirement.

One of our larger steel mills made a survey and careful study of the existing installations and a final decision was that none did meet their particular requirements.

After a prolonged study their engineers came up with what did appear to be a workable and ingenious arrangement from every angle.

The joint efforts of the steel mill engineers and the gas and equipment manufacturer finally resulted in an all-weather installation with very efficient material-handling arrangements.

Figure 14 shows a view of the cutting beds consisting of four flat cars, with a 10-ft. Travograph mounted on a raised track line, which permits cutting in any direction. All electrical gear is weatherproofed. The heavy-duty cutting torch attached to a 3-in. square slide bar permits a vertical motion of 6 ft. 6 in., using a heavy-duty remote control raise and lower mechanism which can be operated by motor or hand.

All control levers readily accessible to the operator. Figure 15 shows the remote control unit with weather-

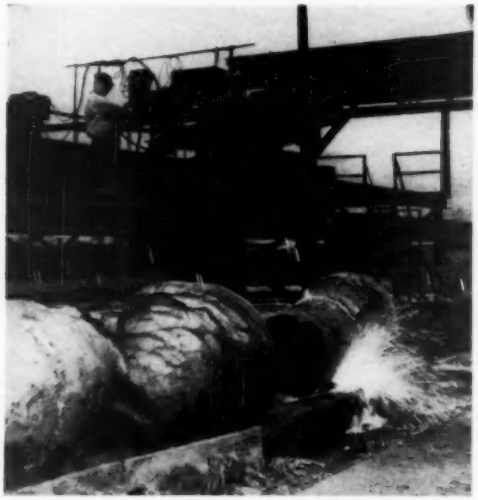

*Fig. 14 A special heavy-duty weatherproof oxygen cutting installation for scrap cutting, using a No. 40 travograph with heavy-duty tracer and heavy-duty cutting torch equipment*

proof housing removed to give access to the working mechanism for maintenance care, adjustment or repairs.

Experience with standard tracer mechanisms very quickly proved that a special tracer would be required for extra power, also that it be of a weatherproof design fully housed. The tracer speed is $^{7}/_{16}$ to $5^{5}/_{8}$ in. in low gear and 4 in. to $22^{3}/_{4}$ in. in high gear.

The weatherproof cover is removed (Fig. 16) to provide access to the mechanism. The driving motor is $^{1}/_{8}$ hp. variable speed governor-type motor. At the lower front is shown a constant speed steering motor with approximate turning speed of $1^{3}/_{4}$ turns per minute. At the upper rear is shown a constant speed elevator motor which raises and lowers at approximately 22 in. per minute. The total weight of the unit is 132 lb. and the floating weight 100 lb. This heavy-duty tracer is remotely controlled except for motor speed changes.

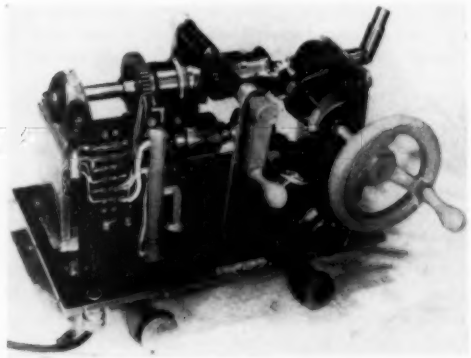

*Fig. 15 Close-up view of motorized and hand control raise the lower device with cover removed to show mechanism*

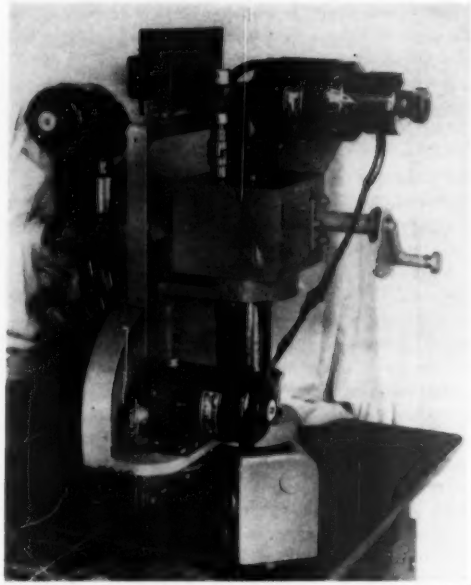

*Fig. 16 Close-up view of heavy-duty remote controlled tracer device with cover removed to show mechanism*

While the large shape cutting machines are used extensively for the mass production of shapes, the small portable Radiagraph type of machine is extensively used for gas cutting of shapes to a layout line.

Extensive use is also made of this machine for final beveling of plates to size. The usual procedure is to mark the cut line upon the workpiece from a sheet metal template, and then mount the track which guides the machine torch unit directly upon the work piece and in alignment with the cut. With a flexible type of track, the weight of the machine causes the track to conform to the contour of the plates which are, as a rule, fairly level prior to gas cutting.

As a consequence the torch follows the predetermined cut with a minimum of adjustment by the operator. An interesting example of cutting a $^{3}/_{8}$-in. alloy steel plate is shown in Fig. 17 where two finished cuts are made simultaneously at 90 and 45 degrees. The piece is approximately 28 in. wide by 14 ft. long.

The track and machine torch unit are mounted directly upon the plate, permitting two parallel cuts to be made quite readily within the desired accuracy and without special equipment.

The portable type of machine has found extensive use for gas cutting. In recent years requirements have been such that the older types of machines did not lend themselves very readily to many jobs nor were they adaptable to a universal field application. The consequence was that an entirely new design was developed to meet

*Fig. 17 No. 10 Radiagraph. Simultaneous cutting of 90- and 45-degree bevel on 3/8 in. alloy steel plate, 28 in. wide by 14 ft. long*

the ever-growing demands for a machine of medium size and so constructed as to be readily adapted to any type of operation.

Figure 18 shows this machine, a No. 20 Radiagraph, equipped for single torch cutting. The motor-driven carriage measures approximately 21 1/2 in. long, 10 in. wide and 6 in. high; weight of the machine is approximately 80 lb. The drive motor is governor-controlled, fully enclosed, reversible, variable-speed, continuous duty and of sufficient power to drive the carriage and equipment at maximum load without exceeding the allowable temperature rise of 55° C. The speed range is from 2 in. to a maximum of 72 in. per minute.

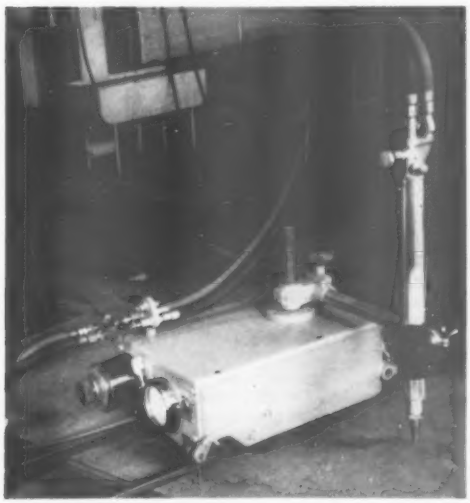

*Fig. 18 No. 20 Radiagraph. Single torch operation, all controls except gear shift at rear. Provides a clear top deck to permit mounting various equipment*

All controls such as governor, clutch lever, tachometer, reversing switch and electric cord connections are mounted at the rear. The gear shift lever is mounted at the front. The top cover plate is flat and it is possible to remove it for easy access to carriage drive mechanism. The removable flat top permits attachment of various kinds of equipment to do cutting, welding, scarfing, flame hardening or softening operations. Guide roller attachments can be applied to either side of the machine to permit operations from a guide strip to follow curved shapes.

The Airco No. 20 Polygraph is a small portable motor-driven, variable speed carriage designed to carry oxygen cutting equipment over a 3-dimensional path, or on degrees of vertical or horizontal planes.

The machine is driven by a knurled roller through a motor drive gear train and is held in contact with, and guided by, a guide roller mechanism which follows a special template which is bent and fabricated to conform to the proposed cut. The template is constructed of a 1/4-in. base plate with an angle member tack welded to this base plate. The machine speed can be set at any predetermined range from 4 to 27 in. per minute and can be driven forward or reverse.

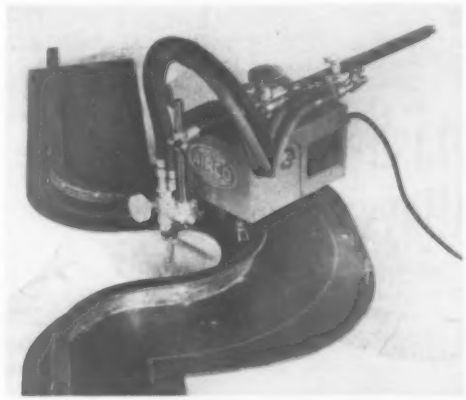

*Fig. 19 No. 20 Polygraph mounted on a horizontal U-type template*

Figure 19 shows the machine traversing a U-shaped template in a horizontal position. It will work on similar templates in a vertical or overhead position.

The method of operation is to select the tip sizes, pressures and speeds required for a given cut on a straight run and then as the intersection of the radius is reached, the speed is decreased or increased to secure a travel speed on the radius comparable to that used for the straight line cut.

Figure 20 illustrates a combination of a horizontal and a vertical template. Templates can be constructed for compound curves or twists and will work equally

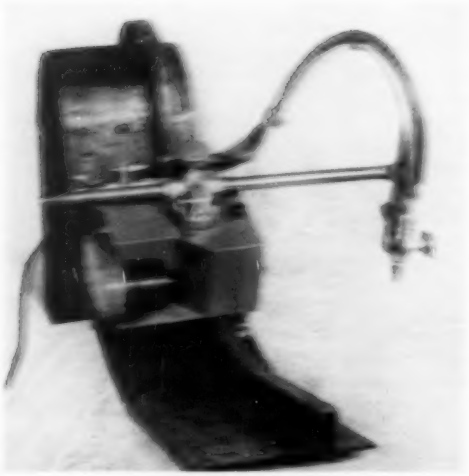

*Fig. 20 — No. 20 Pantograph mounted on a vertical U-type template*

well provided proper attention is given to compensate for the variable burn speed encountered on the various mill that are involved.

This equipment has been found extremely useful for cutting operations in defense work such as ship and naval construction and army tank construction.

## CONCLUSION

The problems confronting us in our corresponding defense program will be carried out to a successful conclusion because of your knowledge, the available plant and machine capacity and the willingness to work and produce those things which are of most importance to the survival of our way of life and freedom. We can look with pride upon the record of performance of our industry in the past and the lessons learned in the past will benefit us much now and in the future.

An understanding of the basic principles of the process, a knowledge and appreciation of good workmanship, a recognition of what is required and an analysis of what improves while cutting are all necessary to obtain the best results. By application of this knowledge to introduce the necessary control of factors, there appears to be little reason for not obtaining accuracy equal to that of any other metal working process.

In fact, it is remarkable that control can be applied to a chemical reaction and an issuing gas stream that makes possible the accurate results produced by gas cutting.

# Flash Butt Welding of High-Temperature Alloys

***Typical specifications including electrical and mechanical requirements for flash welding heat resistant alloys and nonferrous materials used in jet engine production***

*by Dr. I. A. Oehler*


### Abstract

Flash butt welding, a commonly applied high production method of joining carbon steels, is readily applicable to the joining of the various heat-resistant alloys and nonferrous materials used in jet engine production.

The techniques which must be employed for various alloys can be related to those used on carbon steels by comparing physical and electrical characteristics. Thermal treatment after welding is often necessary to realize full physical properties in the joint. The process is particularly adaptable to joining dissimilar materials.

Modern automatic hydraulic flash butt welders are capable of operating over wide ranges of welding variables, so that many different alloys can be satisfactorily welded on a single machine.

Electrical and mechanical requirements for various joint sections are presented. A brief description of typical flash welding specifications covering certification of equipment and production control is given.


THE large number of circular components in a jet engine provides ample opportunity for the application of flash butt welding. For many years some companies have built their business around this

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method of joining to fabricate rims, wheel bands, motor frames, angle rings and similar products. Most of these products have been made of carbon or alloy constructional steels, but some items of chromium and chromium nickel heat-resisting steels have been flash welded for more than twenty years for the refining and dairy industries. The process is commonly employed for joining equal sections of metals and alloys in production quantities in the steel, automotive and other fabricating industries. It is rapid and economical and, when properly controlled, welds of consistent high quality are produced.

A flash-butt weld is made by clamping the pieces to be joined on conducting dies which are part of the welding machine. When the pieces are brought into light contact, an arc is struck between them. As arcing or flashing, as it is commonly called, proceeds, particles of molten metal are violently expelled from the arc stream and heat flows back into the pieces from the arcing surfaces. The dies must be brought closer and closer together to maintain the arc as material is flashed away. Finally, when the proper temperature has been reached, the pieces are forced together rapidly so that metal is upset and expelled from the joint. The current is usually interrupted shortly after upset begins. As a result of upsetting, the weld is consummated some distance back from the arcing surfaces. The molten surface layer and that material immediately behind it has been expelled from the joint. No special joint preparation is necessary because the flashing action is an effective electrical machining operation. It is necessary to have the die contact areas of the work free from scale, oil and dirt to provide good electrical contact.

## THE MACHINE

A flash-butt welding machine is essentially a press-transformer combination with means provided generally through cam-actuated motions and limit switches, for controlling the variables which effect weld quality. These variables are:

1. Flashing voltage.
2. Time, distance and motion of flashing travel.
3. Amount and speed of upset travel.
4. Time of current cutoff after upset begins.

Modern automatic flash-butt welders are capable of operating over wide ranges of these variables so that many different alloys and sections can be satisfactorily welded on a single machine.

For carbon steels, which have reasonably good electrical and thermal conductivity and are quite workable at elevated temperature, good welds can be made over a broad range of the variables. The heat-resisting alloys have low conductivities and are difficult to hot-work. Welder settings are far more critical and the mechanical forces necessary to upset these alloys are great, about 35,000 psi. being welded as against 8000 for low-carbon steels.

It is important when establishing welder setups that the limits of the variables which will produce good welds be established so that final setup can be made well within the limits. This provides protection of weld quality from power line fluctuations and minor variations in the response of the welding machine.

## THE WELDING CYCLE

The major problem of the flashing cycle for high-temperature alloys is in producing a sufficient and uniform temperature throughout the cross section of the joint and extending sufficiently far back toward the dies to permit adequate upset. Because of the low thermal and electrical conductivity of these alloys, it is possible to flash material away faster than heat flows back into the work. The flashing voltage must be low and the time of flashing long, compared to carbon steel. It is good practice to flash near the lowest voltage that will maintain an arc. On sections over $^1/_4$ in. in thickness, manual preheat is highly desirable to insure uniform heating. The pieces are brought into contact under light pressure so that current flows without arcing. Heat is generated at the abutting surfaces until the pieces protruding from the dies attain an average temperature of about 1200°, at which time the flashing cycle is allowed to proceed. Existing specifications generally permit manual preheating provided not more than 15% of the total flashing travel is consumed this way.

The upset portion of the welding cycle is little different from that for carbon steels. A short period of current flow after upset begins is necessary to maintain temperature for proper metal flow, but current should be cut off 5 to 10 cycles after upset begins to prevent overheating. Of course much higher pressures are needed to upset the material.

In establishing welder settings a simple bend test on the joint is most valuable. Welds of good tensile strength can be readily made, but welds of good ductility require much closer control. After good bend tests have been obtained, additional samples are welded from which the usual laboratory tests are taken. Final setup is based on the results of these tests.

After welding, the fabricated part should be annealed or otherwise treated to obtain the same structural condition in the joint as in the parent material. Annealing appreciably improves the corrosion resistance of the joint, even on the stabilized nickel-chromium steels, and some improvement in ductility generally results. Since no filler metal is used, the weld joints respond to heat treatment in an identical manner as the parent metal.

## SPECIFICATIONS

Existing specifications usually provide that the first 10 or more production pieces in a run be tested to destruction to assure consistency of machine performance and that all pieces in the run be proof loaded or examined by some nondestructive means. X-ray exami-

nation is of little use because cracks and oxide films which may exist in the joint and be highly detrimental have been so reduced by upsetting as to give little or no indication on a radiograph.

Weld defects encountered in production runs fall into two general classes, those originating for material defects, and those occurring in the welding process. Flash butt welding does not weld laminations or pipe at the joint as does fusion welding. Such material defects are accentuated by the upsetting at the joint and appear as cracks in the weld area. They are readily detected, but since this process has not been designed as an inspection operation, rigid inspection is necessary on material as received to avoid loss in processing.

Defects which occur in the welding process lie at or near the surface in and adjacent to the joint. During upset a pressure gradient exist from center to surface of the joint and at the center, where pressure is greatest, oxides are most easily expelled and voids readily closed up. The size and appearance of the upset burr is a good indication of the adequacy of the upset in cleaning up the weld. After burr removal, visual inspection of the weld is generally satisfactory for detecting minute cracks.

The most commonly encountered defects are die burns which result from poor electrical contact between the work and the welder dies. These alloys of low conductivity are quite susceptible to localized overheating. Die burns are easily detected by visual inspection. Cleanliness and proper contour of die and work surfaces provide the cure.

A properly made flash butt weld will have physical properties in excess of 95% of the parent material values. For design purposes, therefore, no sacrifice in strength need be made as a result of the joint.

Weld tests between dissimilar materials will usually fail outside the joint in the lower strength alloy. To date such applications have jointed parts operating at high temperatures with steels possessing wear or abrasion resistance. There is promise, however, that the additional factors of weight and strength at ordinary temperature may introduce new ferrous and nonferrous combinations.

Large quantities of flash welded parts have been made using the various chromium and chromium nickel heat-resisting steels, nickel base alloys such as Inconel and Monel, and some of the high-cobalt alloys. Some of the titanium alloys are readily welded. For all of these materials the principles to be followed and the precautions to be taken are essentially the same.

## SELECTION OF EQUIPMENT

The selection of equipment for flash welding is best arrived at by close cooperation with welder manufacturers. The variety of work possible and the frequent design changes encountered in the jet engine field make planning for future use imperative. A general purpose machine for welding circular components of high-temperature alloys should have at least 100,000 lb. upset pressure, twice that amount available for clamping and be equipped with a 600-kva. welding transformer. Such a machine, with fully automatic controls will cost around $50,000. It will be capable of consistently producing welds of high quality at high production rates and can be readily changed over for various sections in accordance with predetermined welding schedules.

## WELDING RINGS

Mention was made earlier of the considerable number of circular components in an engine. Some engines contain 30 or more flash-welded rings. A brief description of the steps in producing a ring may be of interest.

The material is usually received from the producing mill in the hot-rolled condition. Sheared ends are inspected as a quality check and the bars circled on a three-roll former. This may be done either hot or cold, depending on analysis and section. After circling, the bar ends are flattened for a few inches back from each end and brought into abutting alignment. This is done for three reasons. First, it permits the use of a single set of flat welding dies to cover a variety of ring diameters. Second, it facilitates good die contact conditions, and third, it provides for a good upset condition in that the longitudinal axes of the bar ends, and thereby the lines of pressure, are at right angles to the joint.

Prior to welding, scale is removed from the die contact areas by grinding or blasting. Any grease, oil or dirt present is wiped off. Welding proceeds as previously outlined and immediately after welding the upset burr is chipped off while still hot.

Following this, the rings are heated for sizing. For many alloys, this heating serves as a satisfactory anneal. The hot ring is stretched to approximate final size on a segmented expander and then press flattened. Final sizing is usually done at room temperature, again on an expander, to true up the ring. The stretching of the ring, which of course includes the weld joint, serves effectively as a proof test of the weld. Dimensional and hardness checks and visual examination complete the inspection procedure. Rings are then ready either for additional heat treatment or machining.

This method of ring production permits working to close manufacturing tolerances so that machining allowances can be kept to a minimum. Since high-temperature alloys contain metals in scarce supply and the cost of the alloys ranges from forty cents to many dollars a pound, important savings besides the saving in machining time result from these close tolerances. Where quantities justify the investment in mill rolls, special bar shapes, which roughly resemble the machined cross section, are used, and result in further savings in machines, material, money and time.

# Welding of High Heat-Resistant Materials

***Materials used in jet aircraft construction include mild steel, stainless steels, nickel base alloys, and titanium. Their electrical, thermal conductivity and mechanical properties profoundly affect welding procedures***

*by J. L. Solomon*

THE development of the jet propulsion gas turbine was made possible because of the high development in certain methods of sheet material fabrication, one of prime importance being that of resistance welding. The development of the jet engine demonstrated the importance of the various welding processes, such as fusion and resistance welding. Engines for Aircraft had heretofore been fabricated by well-known methods of machining and fabricating heavy castings, forgings and rolled sections. The jet engine, unlike the reciprocating type of engine, is constructed largely of sheet metal, rolled or pressed sections, properly shaped.

Figure 1 illustrates a typical arrangement of parts in a gas turbine unit utilized for jet propulsion. A series of combustion chambers are arranged to receive the air and fuel from the air intakes and centrifugal compressor, and to discharge the gases into the exhaust unit and out the jet pipe. The combustion chambers shown in Fig. 2 consist of a number of sheet metal parts of cylindrical and conical shape, which are fabricated by resistance welding. The components of the combustion chambers include the burner, flame tube head, air casing and the discharge nozzle. The air casings operate at low temperature and are normally fabricated from mild steel which has a sprayed aluminum coating to prevent oxidation. The flame tube undergoes extremely high temperatures and is of a nickel base alloy such as Nimonic 75. The flame tube head is made from a number of pressed or drawn parts which are stitch welded together. The body of the flame tube is made from drawn sections which are seam welded together. Between the combustion chambers and the turbine is the discharge nozzle assembly which consists of nozzles of austenitic steels welded to heavy machined flanges of a tungsten bearing austenitic steel. The exhaust unit, which lies immediately behind the turbine, consists of an outer truncated cone made of 18–8 stainless which is seam welded to a machined flange at each end. An inner cone is supported from the outer

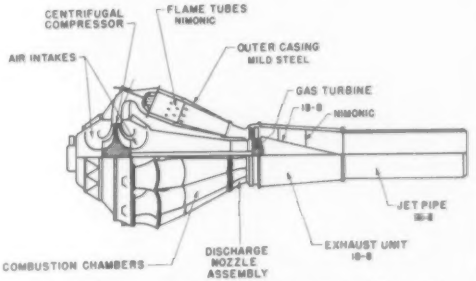


*Fig. 1 Arrangement of parts in a gas turbine unit*

cone by tubes which are shielded from the high velocity gases by air foil sections. These air foil sections are constructed of a Nimonic 75 outer skin, and they are spot welded to inner spacers of 18–8 stainless. The welding of the outer skin to the inner spacers is done by a series resistance welding process.

The jet pipe behind the exhaust unit, and from which the high velocity gases emerge, is peculiar to the installation of the jet engine in each particular airframe. For this reason, the jet pipe is designed and constructed from a variety of materials, such as 18–8 stainless steels types 347 and 321, super-stainless steels such as 19-9DL, and in one particular case of that material of the future—Titanium. In the construction of the jet pipe, both circular and longitudinal seam welding, as well as spot welding, is utilized. The titanium jet pipe is being seam and roll-spot welded on three-phase machines, and it is interesting to note that the

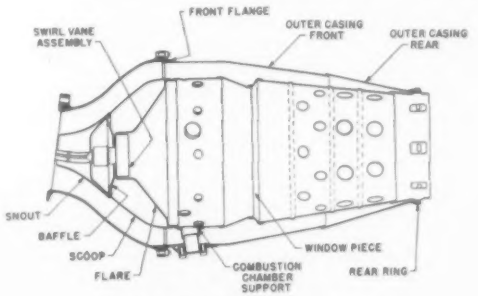


*Fig. 2 Combustion chamber*

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Table 1—Physical Properties of High Heat Resistant Materials

| A.M.S. no. | Other no. | Chromium, % | Nickel, % | Other elements* | Carbon, % | Manganese, % | Silicon, % | Specific heat, btu./lb./° F./ (0–200° F.) | Thermal conductivity, Btu./ft.²/hr./° F./in. (68–212° F.) | Mean coefficient of thermal expansion,† in./in./° F. × $10^{-6}$ 68–212° F. | 68–1825° F. | Electrical resistivity at 68° F.,‡ microhms/cm.³ | Electrical resistivity at 1200° F.,‡ microhms/cm.³ | Ultimate strength, lb./in.², min. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5040 | 1010 | ..... | ..... | ..... | 0.2 ..... | 0.45 ..... | ..... | 0.107 | 460 | 6.5 | 7.8 | 10 | ... | 45,000 |
| 5070 | 1022 | ..... | ..... | ..... | 0.2 ..... | 0.45 ..... | ..... | 0.107 | 460 | 6.5 | 7.8 | 10 | ... | 55,000 |
| 5504 | 410 | 11.5–13.5 | 0.5 max. | ..... | 0.15 max. | 1.00 max. | 0.75 max. | 0.11 | 173 | 5.1 | 7.6 | 57 | 108.7 | 60,000 |
| 5510 | 321 | 17.0–19.0 | 8.0–11.0 | Ti§ | 0.10 max. | 2.00 max. | 0.75 max. | 0.12 | 113 | 9.6 | 11.2 | 71 | ... | 75,000 |
| 5512 | 347 | 17.0–19.0 | 9.0–12.0 | Cb‖ | 0.10 max. | 2.00 max. | 0.75 max. | 0.12 | 113 | 9.6 | 11.2 | 71 | ... | 75,000 |
| 5521 | 310 | 24.0–26.0 | 19.0–22.0 | ..... | 0.25 max. | 2.00 max. | 1.50 max. | 0.14 | 90 | 8.0 | 10.6 | 80 | 115 | 80,000 |
| 5524 | 316 | 16.0–18.0 | 10.0–14.0 | 2.00–3.00 Mo | 0.10 max. | 2.00 max. | 0.75 max. | 0.12 | 113 | 9.6 | 11.2 | 73.0 | 116.0 | 80,000 |
| 5570 | 321 | 17.0–19.0 | 8.0–11.0 | Ti§ | 0.10 max. | 2.00 max. | 0.75 max. | 0.12 | 113 | 9.6 | 11.2 | 71 | ... | 75,000 |
| 5613 | 403 | | | | | See 410—Special turbine steel | | | | | | | | |
| 5645 | 321 | 17.0–19.0 | 8.0–11.0 | Ti§ | 0.10 max. | 2.00 max. | 0.75 max. | 0.12 | 113 | 9.6 | 11.2 | 71.0 | ... | 75,000 |
| 5651 | 310 | 24.0–26.0 | 19.0–22.0 | ..... | 0.25 max. | 2.00 max. | 1.50 max. | 0.14 | 90 | 8.0 | 10.6 | 80.0 | ... | 80,000 |
| | Nimonic 75 | 0.20 | 0.80 | Some titanium | ..... | ..... | ..... | ... | ... | 8.4 | 15 | 110 | ... | 84–100,000 |
| | Nimonic 80 | 20.0 | 74.0 | Al 0.6<br>Ti 2.3 | 0.04 | 0.5 | 0.6 | ... | ... | .. | .. | ... | ... | ..... |
| | Inconel X | 15.0 | 73.0 | Ti 2.5<br>Al 0.7<br>Cb 1.0 | 0.04 | 0.5 | 0.4 | 0.11 | 106 | 7.6 | 9.2 | 122 | 131 | 110,000 |

* Sulphur and phosphorus shown in this column when significant; not shown if normal.
† The Coefficient of Expansion for low-carbon iron is 6.5 range 68–212° F.; 7.8 range 68–1825° F.
‡ To obtain resistivity in ohms/circular mil foot, multiply microhms/cm.³ by 6.017.
§ Minimum Ti = 4 × % C.
‖ Minimum Cb = 8 × % C.

techniques used for welding titanium are quite similar to those used for welding stainless steels. Table 1 gives the physical properties of some of the materials used in jet aircraft construction. These materials include mild steel, austenitic stainless steels, martensitic stainless steels and nickel base alloys. The stainless and high-nickel alloys, such as Nimonic, are characterized by their high-electrical resistivity, low-thermal conductivity and high-tensile strength. These properties of the material affects the methods utilized in resistance welding, and governs the type of welding schedules necessary to produce high-quality welds. For example, the fatigue life of a certain seam-welded joint in an afterburner, which had been originally seam welded, was increased substantially by using an intermittent drive overlapping roll-spot weld, and this at an increase in welding speed.

In considering the welding parameters required for welding high heat-resisting alloys, the welding force is determined by the high-tensile strength of such materials and by the ability of these materials to retain their tensile strength at elevated temperatures. Thus, in comparison with the welding of mild steel, the welding force is relatively high. On the other hand, the high resistivity of the material limits the current density to a value lower than that used on mild steel and other familiar materials of better electrical conductivity. The third property that is different from the materials most commonly welded; that is, low-thermal conductivity, reveals that the weld must be maintained under the electrode force for a sufficiently long time to permit its cooling to a stable temperature, and that sufficient cooling must be provided so that the weld will reach such a temperature quickly. The property of low-thermal conductivity also demands that sufficient cooling be provided in seam welding to achieve a uniform starting condition for each weld.

The problem of joining dissimilar materials having different rates of thermal conductivity is frequently encountered in jet engine manufacture. In this case, a thermal balance is achieved by proper selection of electrode dimensions. In many instances, it is necessary to use two different electrode materials as well, in order to provide proper thermal balance.

Figure 3 illustrates a number of typical flanged sections which are seam welded

to cylinders or truncated cones formed from sheets of various thicknesses and alloys.

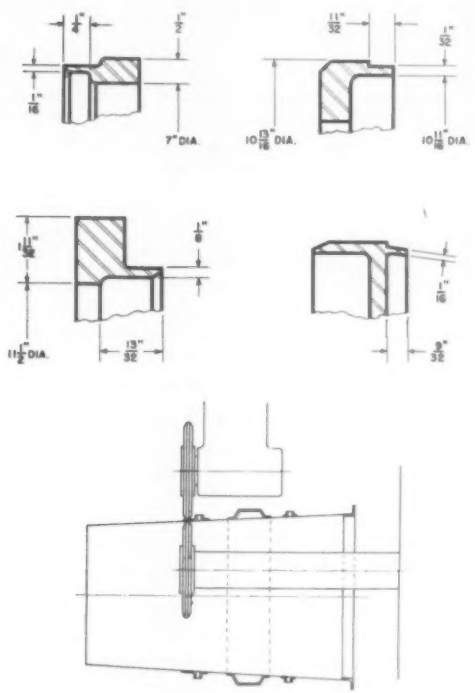


*Fig. 3 Cross-section of typical welds*

Figure 4 shows a typical weld in Nimonic material required in the fabrication of the flame tube of the combustion chamber.

Figure 5 is a cross-section of a typical stitch weld in Nimonic 75. The stitch welding process is encountered

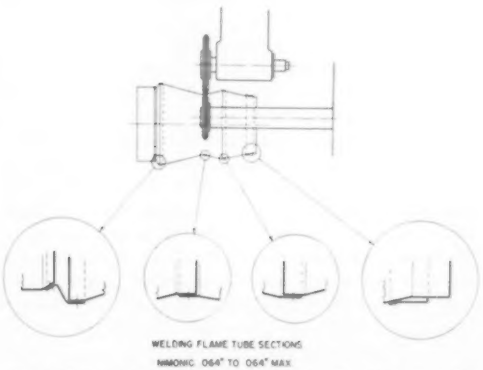


*Fig. 4 Typical welds in flame tube of combustion chamber*

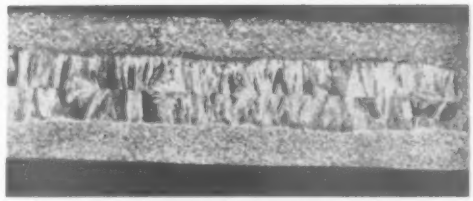

*Fig. 5. Typical stitch welding operation*

a great deal in jet engine design because of the necessity of producing pressure-tight joints on very small diameters. In stitch welding, it is important that the pitch of the welds be kept as uniform as possible, and that adequate external cooling is provided. Perforated tubing, formed in an annular ring around the electrode, is generally used for external cooling.

Remembering the high velocity of the gases that pass through a jet engine, it is clear that electrode indentation must be kept to a minimum in order to maintain good aero-dynamic surfaces. The use of variable pressure in welding aids in reducing indentation and sheet separation. Because of the unique requirements on the design of jet engines, the overlap provided for resistance welding is usually much less than what would be desired. For this reason, extreme care must be taken in the resistance welding process to avoid expulsions of material. In this respect, rigid controls must be placed on the maintenance of electrode tips to provide proper contour, so as to insure correct size of the weld nugget.

In the sheet thicknesses normally encountered in jet engines, a weld nugget of four times the sheet thickness is considered optimum. In some instances, edge distances as low as 0.060 in. have been used in production successfully; however, for ease in manufacturing, greater edge distances are preferred.

Most high heat-resistant alloys are stitch welded with a current density of 250,000 to 300,000 amperes psi. and a force density of 25,000 to 35,000 psi.

The seam welding of high heat-resistant materials from 0.020 to 0.064 in. may be effected by utilizing a heat time up to 8 cycles with a cool time of twice the "on" time. Current densities to 300,000 to 350,000 amperes psi. are utilized with pressure densities of 40,000 psi. The welding of this material in thickness below 0.062 in. may be accomplished satisfactorily by using a straight seam-welding process. In gages above 0.062 in., it has been found advantageous to use an intermittent seam-welding process with a machine cycle as follows:

Instead of the wheels rolling continuously, as in the straight forward seam welding, they are allowed to advance only during those periods when there is no passage of current. During the typical welding operation after the foot pedal is depressed, the head is brought down upon the pieces to be welded after the preset wheel force is established. The first pulse of welding current or series of welding current pulses is

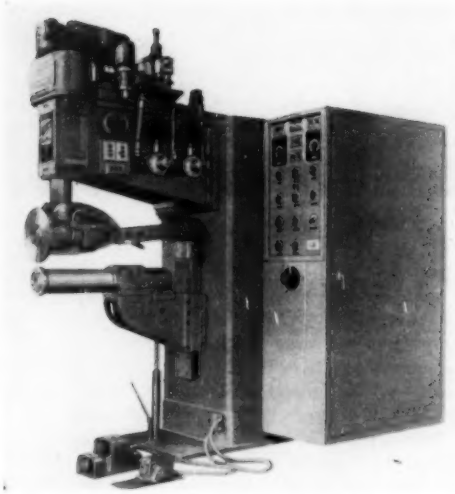

*Fig. 6 Photograph of three-phase seam and roll spot welder*

passed through the material. After this, the material is forged by an increase in pressure, and after a preset forging time, the pressure is lowered and the wheels are allowed to advance to the next spot. The complete process is accomplished by means of fully electronic controls which control the welding current, the forging pressure, the forging delay, and the d.-c. motor.

Figure 6 is a photograph of this machine.

Figure 7 is a diagram of the sequence of operation.

Experience has shown that in seam welding of Nimonic material, it is very important that the number of spots per inch be maintained. In one seam-welding operation the optimum number of spots per inch was found to be 15. If we increase the wheel speed to less than 15 spots per inch, we find that no weld is obtained, or if a weld is obtained, it is cracked—in some cases it is discontinuous. If the wheel speed is decreased, the welding pattern, instead of appearing normal, takes on a zig zag appearance as shown in the lower

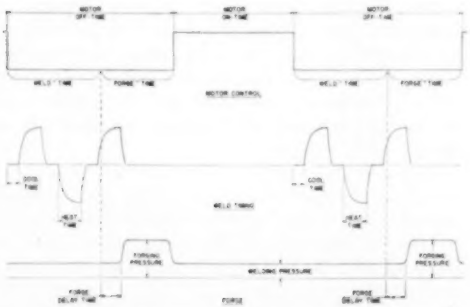

*Fig. 7 Diagram of sequence of operation of seam welder during intermittent roll spot welding*

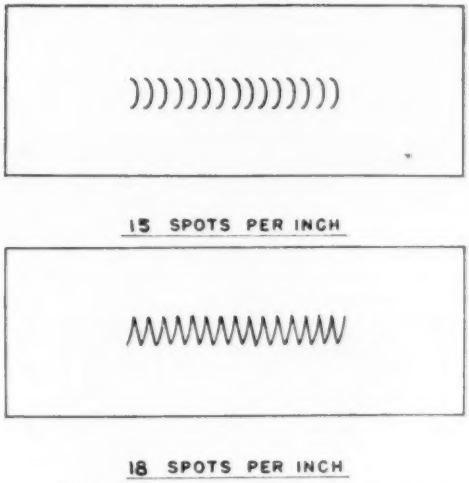


*Fig. 8 Seam weld pattern under various numbers of spots per inch*

part of Fig. 8. This is probably due to the fact that the second weld is shunted so much by the first weld that only that corner of the weld nugget which has the least pressure density will weld. The next weld, since it is not shunted at the opposite end, will obtain higher current at this end of the weld because of the lower shunt effect, and will therefore produce a weld at this point. The next welded point will be at the opposite end and so on with the result that the pattern will have the typical zig-zag characteristics. With a slight increase in wheel speed, this shunting effect is minimized and a regular pattern will be obtained.

In seam welding, the electrodes are machined flat to the width of the weld nugget required. The width of the weld nugget is determined by the available space on the flange which, of course, has been predetermined in the design of the engine. Because of the narrow flanges which are designated in the design, the weld nugget is very often smaller than one would desire and it is therefore necessary to machine the wheels with a narrow flat and to maintain the width of the flat very carefully in order that satisfactory welding is obtained. The electrodes utilized are usually the Class 3; however, in certain cases where dissimilar metals are being welded, it may be necessary to use dissimilar alloy electrodes in order to produce proper heat balance. Furthermore, the design of the electrodes is dependent upon the thickness and thermal conductivity of the material being welded. In preparing for the seam welding, it is very important that the surface of the material be thoroughly degreased. On those materials which have undergone a heat treatment, a very heavy adherent scale will cover the parts. This scale has a very high resistance and must be removed by pickling.

The wide range in overlap of material and the

dissimilarity of the materials being welded make it necessary to study each weld section individually to determine the largest weld nugget that may be obtained at that section, and then determine the pressure and current that would be required to produce a good weld.

In welding 0.031 to 0.043-in. Nimonic, an upper electrode 10 in. in diameter with 0.312 in. flat, and a lower electrode $6^1/_2$ in. in diameter with 0.250 in. flat were utilized. The overlap was 0.750 in. and the resulting weld nugget was 0.200 in. wide. Another welding problem is the welding of 0.062 in. plus 0.062 in. Nimonic with an overlap of only 0.405 in. In this case, the same electrodes were used and the weld nugget diameter was 0.250 in. Because of this small overlap, this welding operation would tend to be more critical than the former since the edge distance from the weld is less than 0.075 in., whereas in the former case, the edge distance is 0.275. Another example is the welding of 5615 material 0.040 in. thick to Nimonic-75, 0.031 in. thick. The overlap in this case is only 0.355 in. and the electrodes are reduced now to 0.218 in. for the upper electrode and 0.187 in. flat for the lower electrode in order to confine the weld. Due to the small overlap, this welding operation is still more critical.

In early experience, single phase welding equipment was used exclusively for the manufacture of jet engines, and it was found that it was quite difficult to obtain consistently high quality welds in production operation, especially on those jobs having narrow overlaps and in joining high heat-resistant alloys. Due to the high resistivity of the material and the low-thermal conductivity, the build-up of current in the spot when single phase was utilized, was so rapid that the localized spot temperatures were extremely high, and expulsion of material resulted. Since the rapid increase of current during the first half cycle produces expulsion of material, it is necessary to hold the pressure density and current density between very close limits in order to obtain satisfactory welds. Furthermore, the high current density at the edge of the welding electrodes, due to the skin effect phenomena, produces increased heating at the edges of the electrodes, causing mushrooming of the electrodes and consequently allows very little welding with a set of electrodes before it becomes necessary to replace them. For example, it has been found at the English Rolls Royce plant, where the Nene engine was developed and first produced, that they were unable to obtain more than 36-ft. of welding before changing the seam welding electrodes in the welding of 18–8 or Nimonic of 18 gage. The pressure utilized was 850 lb.—welding speed, 1 ft. per minute—heat time, 8 cycles—cool time, 8 cycles. In the welding of thinner gages, 21 to 24 gage, with an electrode force of 450 lb. and a welding speed of 3 ft. per minute, an electrode change would be required after 180 ft. of welding.

When production started in the United States on the same engine, the manufacture installed both single phase and three phase welding equipment on his production line, and from his experience in welding parts on both types of machines, it was found that there were definite advantages in the use of the three-phase equipment. For example, the matter of edge distance and overlap lost their importance, and it was found that when using the three-phase equipment, edge distance of 0.060 in. from the periphery of the tip to the edge of the sheet could be tolerated. Furthermore, because of the decreased skin effect phenomena, there was less tendency for the electrodes to mushroom with a consequent increase in the number of spots that could be obtained in spot welding and the length of the run that could be obtained with a set of electrode wheels. For example, several thousand spots may now be obtained in the spot and stitch welding of Nimonic and 18–8 stainless steel. The average length of life of a set of electrode wheels, when welding 0.048 in. plus 0.048 in. Nimonic, is approximately 350 ft.

Another important factor which makes for less rigid controls and easier welding when using the three-phase equipment is the matter of shunting effect. Because of the high resistivity of these materials used in the jet aircraft, the resistance of the spot is high in proportion to the total impedance of the circuit having this resistance, but the adjacent spot has a pronounced effect upon the distribution of current through the previously welded spot and the spot to be welded. Without shunting, the resistance of the material being welded may be equal to the short circuit impedance of the throat and transformer of the welding machine; however, because of the higher impedance of the secondary of the single-phase machine, a change in the resistance of the load does not effect, to any great degree, the total current passing through the secondary circuit. Therefore, when a previous spot exists close to the spot being welded, a great percentage of the current is shunted to the previous spot and there is not sufficient current through the second spot being welded to produce a weld. It is therefore necessary to increase the secondary current by changing the tap or changing the setting of the heat control in order to produce a weld for the second spot. If the spacing between the first and second spot varies, it becomes quite difficult to compensate manually for the change in the distribution of the secondary current. With the three-phase welder, since the impedance of the secondary is so small, as low as 40 to 50 microhms, the resistance of the material being welded represents a great percentage of the total resistance of the welding circuit. Any change in the resistance between the electrodes, that is in the resistance of the material, caused by thickness change or shunt path adjacent to the spot being welded, causes an almost proportionate change in the secondary current. When making two adjacent welds—when the second spot is being welded, the lowered resistance of the secondary circuit, due to the first spot, automatically increases the secondary current and there is sufficient current developed through the spot being welded to produce an acceptable weld.

Other plants on the continent heard of the work being done in the United States, and they immediately proceeded to run checks to verify this information, and their experience regarding the benefits derived when using the three phase equipment for their jet engine manufacture is as follows:

1. The mill tolerance on rolled sheet can be widened because the three-phase machines, being self-adjusting, allow one to obtain satisfactory results in spite of variations of thickness of the materials due to mill tolerances. Previously, they had to carefully gage every sheet and adjust the machine controls accordingly. They found that this was not necessary when using three-phase machines.

2. The controls required on diameter and width of electrodes are much less critical than for the single-phase machine. (This is due to the fact that with the three-phase equipment when the electrodes increase in diameter slightly, the resistance of the load circuit decreases slightly, and the secondary current increases so that the current density adjusts itself in the right direction.)

3. Flanges can be much narrower without expulsion of metal.

4. Satisfactory welding results are obtained with less supervision and less care than required with single-phase equipment.

5. The condition of the surface of the material is not quite as critical.

6. The rejection of material has been reduced greatly since the introduction of the three-phase equipment.

7. The power consumption is lowered and other electrical advantages are realized from the use of the the three-phase equipment.

As a result they are utilizing the three-phase equipment on all of their critical applications, the single-phase equipment being utilized for such operations as tack welding or welding of non-critical parts.

As the production of jet aircraft increases and as the supply of the critical materials, such as nickel and chromium which are required in the alloys used at present, becomes scarce or limited, there will be increased activity metallurgically toward the development of new alloys with as good or better properties necessary for jet aircraft work which will not require as much of the critical materials. These new alloys will require new experiments to determine the most suitable welding methods, and we foresee that there will be great advances in the technique of welding and in welding machine control which will be necessitated by the new problems arising in the welding of these new materials. Steps in the direction of wave shaping, pressure variation during the welding operation, along with intermittent welding for continous seam-welding applications will be utilized to a greater extent in the future.

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(*Continued on page 241*)

# Drill Press from Electric Drill

*by E. L. Dreher*

THIS drill press will make a valuable addition to any workshop. It makes it easier to drill holes accurately, and puts drilling operations on a production line basis.

First make the base. Cut it out from 3/8-in. plate. Countersink four holes along the edges for fastening to a work bench. Add the shaft. It can be welded to the base without using a nut. However, threading the shaft and using a nut will make the drill press a "smaller package" when it is stored away.

Next, cut out the frame from 3/8-in. plate, or make it by braze welding pieces of plate together. Braze weld a piece of 1 1/2-in. pipe across the frame at each end; then cut out the center portion. Welding the pipe first keeps the sleeves at the ends in perfect line. Get a compression spring to fit between the sleeves. The inside diameter of the spring should be at least 1 9/16 in.

E. L. Dreher, 2950 N. San Antonio Ave., Claremont, Calif.

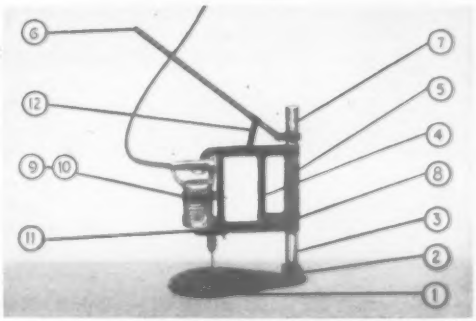
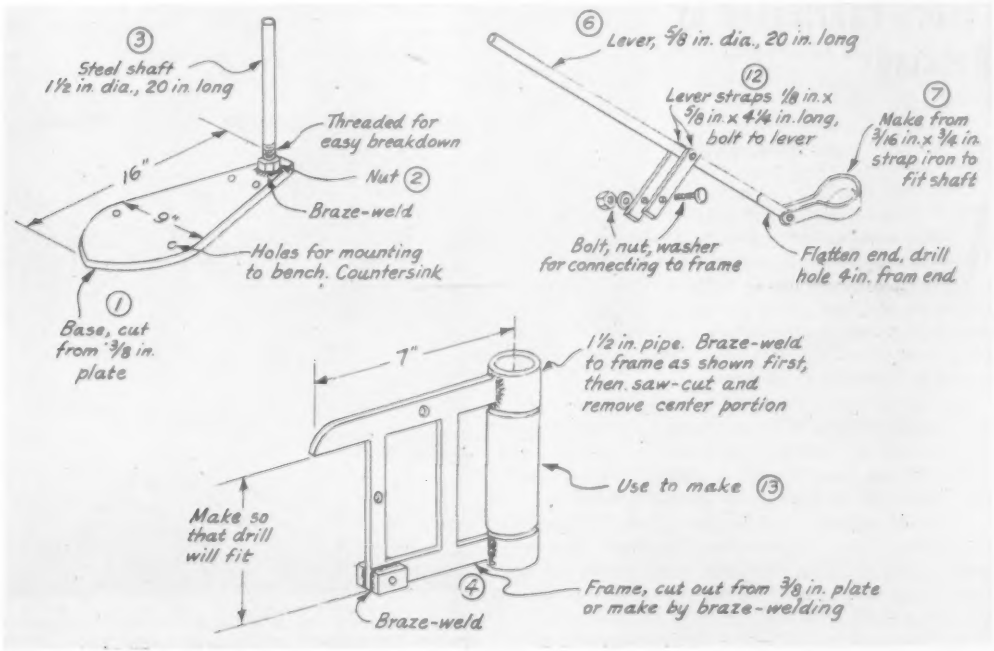
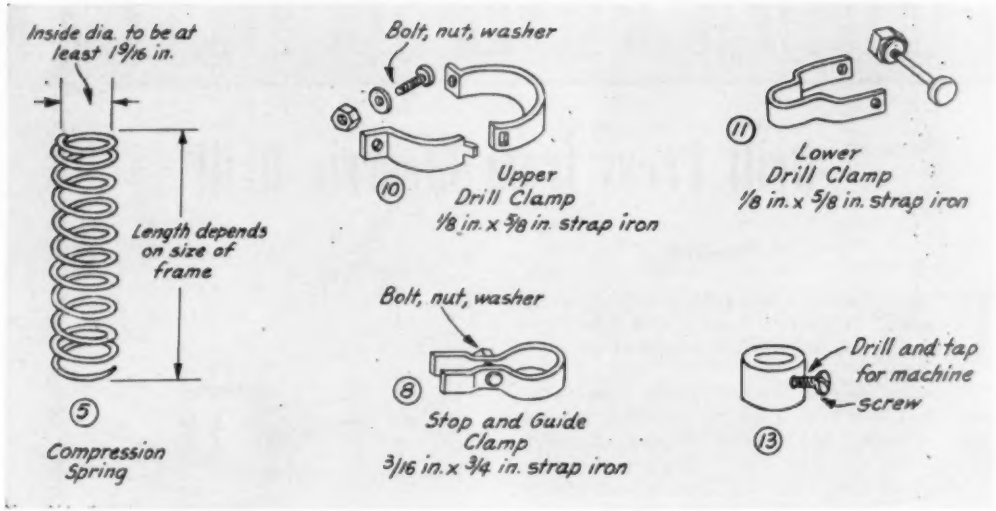



*Fig. 1 Photograph of the homemade drill press. The numbered parts are shown in detail in the sketch below*

Now make the lever and clamps. Shape the clamps to fit your drill. Use strap iron, and heat and bend the clamps to fit around the contours of the drill.

If you like, make a collar from the pipe that was cut


3
Steel shaft 1½ in. dia., 20 in. long
Threaded for easy breakdown
16"
Nut 2
9"
Braze-weld
Holes for mounting to bench. Countersink
1
Base, cut from 3/8 in. plate
6
Lever, 5/8 in. dia., 20 in. long
12
Lever straps 1/8 in. x 5/8 in. x 4¼ in. long, bolt to lever
7
Make from 3/16 in. x ¾ in. strap iron to fit shaft
Bolt, nut, washer for connecting to frame
Flatten end, drill hole 4 in. from end
7"
1½ in. pipe. Braze-weld to frame as shown first, then saw-cut and remove center portion
Use to make 13
Make so that drill will fit
4
Frame, cut out from 3/8 in. plate or make by braze-welding
Braze-weld




away to control the depth of hole to be drilled. This is shown by *13*. Locate the collar on the shaft just above the stand.

Assemble the drill press. Paint the frame, spring, nuts and bolt heads red, and the balance of the drill press back.

---

# New-Type Aluminum Hatch Covers Fabricated by Sigma Welding

*by W. F. Ruehl*

NEW-type aluminum hatch covers, fabricated by sigma welding, had to pass rigid tests before being accepted by the American Bureau of Shipping. The cargo covers had to withstand a lot of rugged testing to simulate actual service conditions. They were loaded heavily, dropped on a concrete floor from great heights and hit with heavy weights—but they passed all tests with flying colors.

The hatch covers consist of a welded frame made from pieces of $^1/_4$-in. thick aluminum. Outside pieces of the frame are extruded—a groove along the top edges provides a seat for the top plate. Two holes are punched in this plate for cast aluminum handles.

After the members that make up the frame are clamped to a jig, they are welded together. The required butt and fillet welds are easily made with a sigma hand-welding unit. A $^3/_{32}$-in. consumable electrode is used. It is supplied as a continuous coil of aluminum wire which is deposited as filler metal cross the arc into the weld. Welding speed is about 25 in. per minute.

It takes about 15 min. to weld the frame. Then the top plate and handles are welded in place.

***Fig 1 — Aluminum hatch covers fabricated by sigma welding had little difficulty passing rugged shock and load tests***

**W. F. Ruehl** is connected with the Linde Air Products Co., Baltimore, Md.

A continuous weld is made between the top plate and frame. After light grinding, the weld is barely visible. The top plate is also skip welded to the frame on the underside.

Since in sigma welding the arc is maintained in a shield of argon gas between the filler metal electrode and the workpiece, welds made by this process are clean and smooth. No flux is used. Sharp reduction of cleaning and finishing costs cuts over-all production cost.

# Brazed Windows

"BETTER Because Its Brazed" might well be the slogan of Aluminum Products Co., 1901 Franklin Ave., Houston, Tex., manufacturers of double-hung windows marketed under the name "APCO." Their windows are fabricated of 63S-T5 extruded aluminum.

Original designs called for mechanical joints at the corners, which proved to be excessive in cost and not satisfactory. With the help of The Smithweld Co., Houston, associate of Big 3 Welding Equipment Co., they redesigned the windows, substituting brazing for the mechanical joints.

Key to the success of the redesign was the adoption of Sheet Aluminum Brazing Rod and Brazaloy Flux for all brazed joints. Reason for selecting this rod and flux was that the low working temperature (1050° F.) would permit the operation to be performed without danger of burn-throughs—the rod is applied at a temperature so much lower than that at which the base metal melts. The Brazaloy Flux gives an exact indication of the joint being ready for application of the rod. It changes its form and appearance at the exact instant when this occurs.

Girls are employed to do the brazing work and not one girl that is employed by them for this type of work has ever had any previous experience in either welding or brazing. The manufacturer considers that this solution of this problem has proved to be a cheap and entirely satisfactory one. The joints not only have the neat appearance which consumers demand but are easy and quick to do and are as strong or stronger than the base metal. Since this design and method have been adopted, a great many other methods have been offered including the inert gas methods using argon or helium. None of these have been able to beat or equal the brazing technique employed.

*Photo and data through the courtesy of All-State Welding Alloys Co.*

Technique is to (1) jig the frame parts in place after the braze area has been cleaned and degreased (edges require no beveling), (2) paint wetted Brazaloy Flux along joint, (3) heat until flux becomes liquid, then (4) apply Aluminum Brazing Rod, melting off sufficient to flow along the joint.

After brazing the windows are cleaned by a 5-min. bath in engraver's nitric acid solution 42-B-E, which is about 35% solution. They are then washed clean in water and sprayed with a clear lacquer.

# Current Welding Literature

(*Continued from page 238*)

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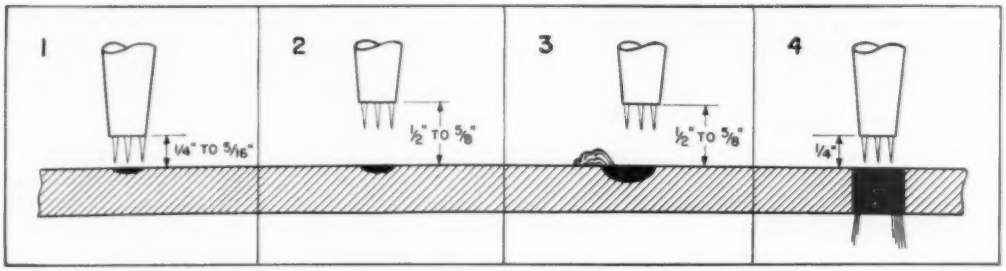



# A Fast Way to "Drill" Holes

*by A. W. Anderson, Jr.*

HERE'S how to use the oxyacetylene blowpipe to cut holes in steel plate. Flame adjustment is the same as for ordinary oxyacetylene cutting. Holes for rivets, bolts and anchors are easy to make by following this technique:

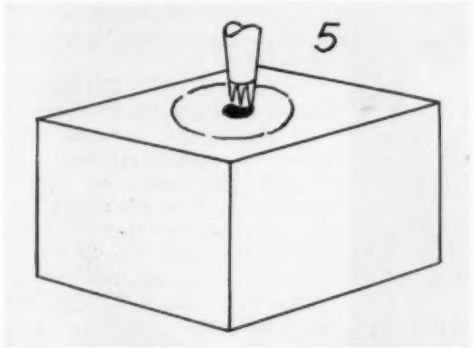
Figure 1. Hold the blowpipe steady and preheat a spot until it turns light red. Keep the end of the nozzle about 1/4 in. from the plate so that the inner cones almost touch it.

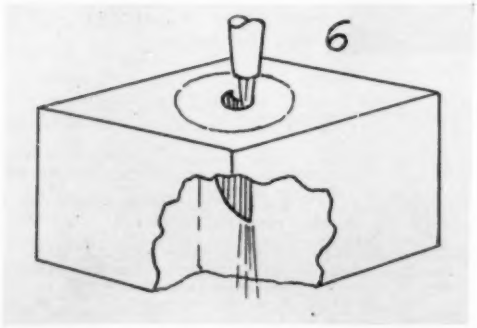
Figure 2. As soon as the spot turns light red, raise the blowpipe a little as shown. The surface will start to melt. If you do not raise the blowpipe, the slag may blow up and clog the nozzle orifices.

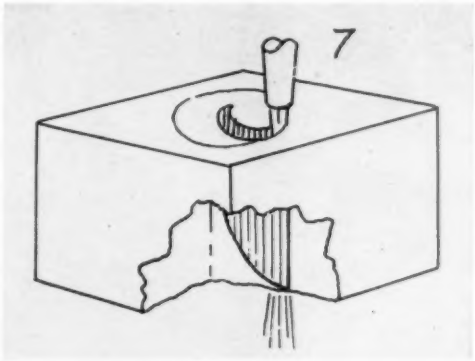
Figure 3. Depress the cutting oxygen lever slowly so that the slag does not blow and scatter. At the same time begin moving the blowpipe in a small circle. This helps control the slag by washing it to the opposite side of the puddle.

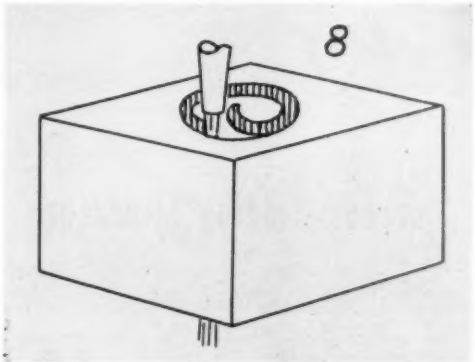
Figure 4. Keep the end of the nozzle about 1/2 to 5/8 in. away from the plate and continue the circling motion until the cut is through the plate. Then lower

A. W. Anderson, Jr., The Linde Air Products Company, a Division of Union Carbide and Carbon Corp., Dallas, Tex.



the blowpipe as shown here. Continue the same circling motion until the hole is of the desired diameter.

### CUTTING HOLES IN THICK SECTIONS

Figure 5. First mark the outline of the hole with chalk or a scriber. Hold the blowpipe at a point inside the outlined area, so the cut will start in the section that is to be discarded. Heat the surface almost to melting.

Figure 6. Gradually press down the cutting oxygen lever and at the same time begin moving the blowpipe toward the line. Hold the nozzle perpendicular to the surface.

Figure 7. Move the blowpipe toward the line slowly and press down on the lever gradually. Try to do this so that when you reach the line, the cut will have penetrated through the entire thickness and the valve will be open all the way.

Figure 8. When you reach the line, slowly move the blowpipe along it. Keep the blowpipe steady, and the valve open all the way. Finish the hole by cleaning off the narrow section near the point of starting.

---

# Builds Own Setup for Welding Flux Recovery

FARRAR & Trefts, Inc., Buffalo, N. Y. have installed with this automatic welding setup a new system for recovering flux employed in submerged arc welding. Welds are produced by a Lincoln LAF-2 automatic welder using a No. 780 Lincoln Flux. Only a small proportion of the flux is consumed in making the welds and much flux can be recovered and reused.

As the welding head is mounted on a boom that can be used in making longitudinal welds up to 24 ft. in length, especially on large cylindrical vessels, an ordinary suction recovery setup would be somewhat cumbersome and inconvenient. Consequently, engineers of the company designed and installed the recovery system illustrated in Figs. 1 and 2. Flux coming from the welds falls or is pushed to the floor below the welding machine and reaches or is swept onto a screen at floor level.

This screen covers part of a pit and whatever passes the screen falls into a trough at the bottom of which is a screw conveyor. In Fig. 1 a part of the screen and of the conveyor are seen. At the delivery end of the conveyor is a suction line through which the flux and any foreign matter such as steel particles that have passed the screen are drawn off and delivered into a primary separator as indicated in the schematic diagram.

From this separator, air and dust are drawn into a vacuum tank or dust separator and the solids settle into a hopper from which they are deposited on the belt of a magnetic separator. This, of course, removes any steel particles, deposits them in a scrap bin and delivers the recovered flux into a storage bin. Air and dust entering the vacuum tank are there separated, the dust falling into a hopper and air being drawn off by the exhaust fan.

Only particles that pass the screen below the welding setup enter the recovery system. As adjacent floor is either steel plate or concrete, relatively little foreign matter is collected and this, including any containing steel particles, is readily separated out, leaving the recovered flux ready for reuse. Naturally, this results in considerable economy, as opposed to using only new flux, and the savings are expected to fully justify the cost of the installation.

*Fig. 1 Looking into one end of the pit below the welding setup. Flux falls or is swept onto the screen, one end of which appears at the left, and falls into the trough containing a screw conveyor that feeds flux into the collecting and cleaning system, Fig. 2*

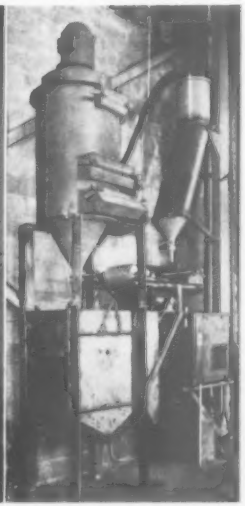


*Fig. 2. Flux recovery system for use with automatic welding set-up. Included are dust separators, a magnetic separator belt and containers for flux-recovered scrap and dust*

# the AMERICAN WELDING SOCIETY

## activities • related events

### Bound Volume 1951

Bound Volumes of THE WELDING JOURNAL for the year 1951 are available in black imitation leather covers, together with a comprehensive subject and authors index. Price $15, including postage.

This volume, comprising a total of 1156 pages in the JOURNAL and an additional 624 pages in the *Welding Research Supplement*, represents a veritable encyclopedia of information in the welding field. Copies may be ordered through the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

### AWS By-Law Revisions

***(Approved by Board of Directors at Meeting Held Jan. 23, 1952, at Washington, D. C.)***

*Article XII, Section 7*

*National Nominating Committee.* A National Nominating Committee consisting of eight members. The Committee shall consist of a Chairman, who shall be a Past-President of the SOCIETY, and seven District Representatives who were elected the previous year to the National Nominating Committee. *The Chairman shall be appointed in the year previous to his term of office.* Announcement of the personnel of the Committee shall be made through publication in the *October* issue of THE WELDING JOURNAL. *The Committee shall hold an open meeting at the time of the Annual Meeting, at which time members may appear to present and discuss the eligibility of candidates for the various offices falling vacant.* The Committee shall deliver to the National Secretary in writing, on or before the *1st* day of May of that year, the names of its nominees for the various elective offices next falling vacant with the written acceptance of each nominee. (District Vice-Presidents and District Representatives shall be nominated by each District Nominating Committee. See Article VI, Section 6.)

*Article IX, Section 1(c)*

The Nomination Ballots must be placed in a plain envelope and sealed; then inserted in a second envelope and sealed. The voter shall then sign his name thereon in ink and mail it to the Secretary. The Secretary shall certify to the competence and signature of all voters returning endorsed nomination ballots and shall then deliver them unopened to the *Tellers of Election.* (*See Section 7 of this Article.*)

A nomination ballot without autographic endorsement of the voter written on the outside envelope shall be considered defective and shall not be canvassed by the *Tellers of Election. The Tellers* shall first open and destroy the outer envelopes of all properly endorsed ballots, and shall then open the inner envelopes, canvass the ballots and certify the results to the Secretary. If no nominations, other than those proposed by the Nominating Committees, are made by twenty-five (25) qualified members, then the Secretary shall treat the nomination ballots as Election Ballots and shall cast the ballot for the election of the candidates so nominated.

*Article IX, Section 7*

*Tellers of Election. The President shall, on or before the first day of July, appoint three (3) Tellers of Election whose duty shall be to canvass the votes cast for nominees and, when necessary, for election and shall certify the same to the Secretary.* At the Annual Meeting this Committee shall certify to the President or to the Presiding Officer, the names of the duly elected officers. Their term of office shall expire when their report of the canvass has been presented and accepted.

### New Sustaining Members

**Industrial Minerals & Chemical Co., Sixth & Gilman Sts., Berkeley, 10, Calif.,** successfully reclaiming fused welding flux or slag suitable for re-use at a considerable saving of the cost of new flux. Each customer's material is kept in separate lots, milled, demetallized, properly sized and returned comparatively dust-free in new paper bags. It also reclaims new flux that is contaminated with foreign material or moisture. It has been producing and refining a large variety of clays and nonmetallic minerals including high-test silicas for over 20 years. It is now devoting one entire section of its plant to the reclaiming of flux for its many customers from Washington to Arizona and west.

Forrest Rhoton—Sustaining (A) Member Representative.

**Welding Machines Mfg. Co., 17325 Lamont Ave., Detroit 12, Mich.,** established in 1931 for the manufacture of resistance welding equipment. The company was a pioneer in the developing of gun-welder units, and has since branched into a full line of resistance equipment, maintaining its own engineering, transformer and structural departments, along with a fully equipped, modern machine shop. The company has representatives in all industrial sections to better serve the resistance welder users. H. V. Beronius, Jr.—Sustaining Member Representative, Detroit, Mich.

## Employment Service Bulletin

### Positions Vacant

Chief Engineer. Stainless steel tube operation. New and expanding small company with excellent prospects. Direct full data to President, Damascus Tube Co., Greenville, Pa.

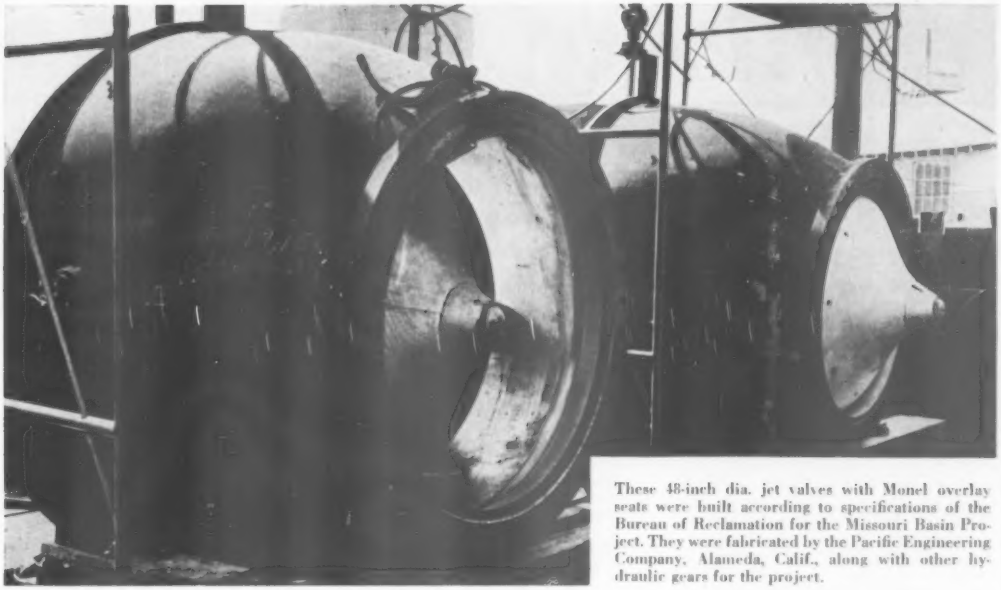
V-265. Welding Foreman for plate and structural pressure vessel manufacturer, using Unionmelt, Heliarc, Sigma and Metallic arc processes. Steel and aluminum are primary metals; also some stainless, Monel and other nonferrous metals. Must be an excellent operator capable of instructing on-the-job training operators. Well-established progressive company in a Mid-western location. Write, giving experience, personal data and salary requirement.

V-266. Welding Engineer. Large eastern metal-producing company has excellent opening for development and technical service work in welding. State age education and experience.

V-267. Assistant Welding Research Engineer. Recent graduate, metallurgical or electrical engineer with welding training. Research and development in welding processes, design and application of mild steel, low-alloy steel, aluminum and stainless steel. Transition temperature studies. Applicant must be resourceful. Good opportunities for promotion. Pullman Standard Car Manufacturing Company Research and Development Department, 1414 Fields Street Hammond, Indiana.

### Services Available

A-625. Welding Engineer. Diversified metal fabricating experience covering all phases of welding. Good administrator with ability to get results in terms of quality and production. Prefer a progressive organization that recognizes ability beyond ordinary standards, able to contribute far above average, and in return expect incentive or bonus plan. Consider Midwest only.



These 48-inch dia. jet valves with Monel overlay seats were built according to specifications of the Bureau of Reclamation for the Missouri Basin Project. They were fabricated by the Pacific Engineering Company, Alameda, Calif., along with other hydraulic gears for the project.

# 50 pounds of Monel Overlay

## *give 10-ton valves durable seats*

These 48" diameter jet valves for the Boysen Dam, Wyoming, are designed with special features to reduce cavitation.

And one of the most important features of the design is the Monel-faced valve seat.

The Pacific Coast Engineering Company, fabricators of the ten-ton valves, made the seats this way:

First they machined a circumferential groove around the interior of the valve body in the position where the seat was to be. Then they built up Monel weld metal in the groove—using 50 pounds of Monel electrodes for each valve. Finally they machined the excess weld metal down to conform to the specifications of the design.

Why did the engineers specify Monel overlay? For three good reasons:

- Its high resistance to cavitation and erosion as well as corrosion.
- Its ability to fuse well with the steel of the valve body without cracking.
- Its good non-galling characteristics when in contact with the bronze ring on the needle nose.

You, too, can depend on Monel electrodes for sound, machinable overlays which resist corrosion and erosion.

Right now, Inco welding materials are on extended delivery because defense needs require so much. Therefore, it will pay you to keep in touch with your distributor regarding available supplies. And remember, Inco's Technical Service Section is always ready to help you with your special welding problems. Just write giving full details.

INCO
TRADE MARK

**THE INTERNATIONAL NICKEL COMPANY, INC.**
*67 Wall Street, New York 5, N.Y.*

# PERSONNEL

### Ninety Years Young

The AMERICAN WELDING SOCIETY offers its congratulations to Past-President Dr. D. S. Jacobus, who attained his ninetieth birthday on January 20th. Dr. Jacobus is in good health although saddened by the recent loss of his lifetime partner, Mrs. Jacobus. Dr. Jacobus resides in Montclair, N. J.

### Arcrods Announces New Officer

W. E. Brainard has been elected president and director of Arcrods Corp., replacing J. H. Humberstone who has become chairman of the Board.

Mr. Brainard joined Arcrods Corp., in 1939 as superintendent of the Cleveland plant and five years later became director of production. He was appointed assistant to the vice-president in 1946 and elected vice-president in 1948. Mr. Brainard is a graduate of Cornell University and a licensed professional engineer. He is an active member of the AMERICAN WELDING SOCIETY and the American Institute of Electrical Engineers.

## OBITUARY

### Allan Ramsay Moon

Allan Ramsay Moon, formerly Secretary of the Institute and later Director of the British Welding Research Assn., died of heart failure on Dec. 16, 1951, and was buried at sea.

Mr. Moon was born on Sept. 28, 1898, in Melbourne. He served with the Australian Forces during the whole of the first World War, and on returning to Australia, entered Melbourne University where he graduated with the degrees of Bachelor of Arts and Bachelor of Civil Engineering. He interested himself in the application of welding to steel structures at an early date, and was responsible for drafting the first Australian Standard Specification of Metal Arc Welding.

He went to England in 1931 as a representative of the E. M. F. Electric Co. (Pty.) Ltd. to establish a business in the manufacture of welding electrodes and equipment. This venture was not successful, and in August 1933 he joined Murex Welding Processes Ltd. as their design engineer.

In February 1937, he left the company to become Secretary of The Institute of Welding, then a comparatively new body.

*Ramsay Moon*

Here his passion for investigation and research was soon felt, and when the British Welding Research Council was formed soon after, he became Secretary to the Council in addition to his ordinary duties. In 1943, he became Director of Research to the Council and in 1945, when this body was split off from the Institute to become the British Welding Research Assn., he became the first Director.

At the commencement of the war he was instrumental, under the guidance of Dr. Gough, Controller-General of Research &

(*Continued on page 276*)

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# Give your welder a chance to be proud of his footage!

It's *waste welding time* when welders have to climb over, prop up or flop the work piece to get at the different seams.

It's *all arc-time* when Worthington-Ransome Turning Rolls and Welding Positioners are used. All welds can be tilted or turned into position—without delay—for continuous downhand welding.

Result—up to 50% more footage, *better* welds (using higher current and heavier rods), less welding rod waste.

Write Worthington Pump and Machinery Corporation, Dunellen, New Jersey, for bulletins or additional information.

With one set-up, work piece may be tilted and rotated for either automatic or manual welding. Welding Positioner capacities from 100 lb to 30 tons.

Production goes up on manual or automatic welding, whether repetitive or job work. Turning Rolls from 3 to 150 tons, stationary or self-propelled.

**WORTHINGTON**

V1-1

# NEWS OF THE INDUSTRY

## Women's Society of Engineers to Be Represented at Centennial of Engineering

For the first time in the history of the engineering profession, women will participate as a separate body in a national meeting of their career group when the recently organized Women's Society of Engineers joins with the other engineering groups of the country in celebrating the Centennial of Engineering in Chicago next summer.

The addition of the new feminine touch to the Centennial program was announced by Major Lenox R. Lohr, its president.

The new women's engineer group was formed late this year and already includes more than 200 members from all sections of the country, and representing various branches of the engineering profession. It is headed by Miss Beatrice Hicks, an executive of the Newark Control Co., Bloomington, N. J.

## Kellogg Fabricating 50,000,000 Lb. of Special Piping

The complexity of the chemical processing behind an atomic bomb was further indicated recently by the announcement that The M. W. Kellogg Co., refinery engineers and metal fabricators of New York City, has been awarded a $75 million contract for the field-fabrication and erection of the process and auxiliary piping and related equipment in the two major gaseous diffusion units now well underway at Paducah, Ky.

The processing sections of the plant are considered the ultimate in complexity, according to Kellogg, and are designed for resistance to corrosion as well as low temperature operation. These Paducah plants are very similar to the K-25 installation at Oak Ridge, which Kellogg, through a specially formed subsidiary (The Kellex Corp.), engineered during World War II. They separate the fissionable isotope, U-235, from uranium hexafluoride, a gasified compound including both the normal uranium and its "explosive" isotope.

To meet the emergency completion schedule, Kellogg is training welders in a special school set up at Paducah. These men are being put on the job as soon as they pass Kellogg requirements. When completed, the entire project will take up about 7500 acres, of which about 20% will be deeded to Tennessee Valley Authority for an $88 million steam power plant some five miles from the plant. This, and an equally large power plant constructed by private industry, will supply a constant power load of about one million kilowatts.

## RWMA President

The Resistance Welder Manufacturers Assn. announce the election of J. R. Barefoot, Jr., of 2261 Fifth Ave., Youngstown, Ohio, as their president for the coming year.

The Resistance Welder Manufacturers Assn., was formulated to improve relations between individual manufacturers, foster higher ethical standards throughout the industry, encourage the adoption of practices and methods to make for greater economy and efficiency, improve the product of the industry, and expand the use of and enlarge the market for resistance welding equipment.

The new president was graduated from Penn State College and has been employed in various capacities by The Federal Machine and Welder Co., Warren, Ohio, since May of 1941. In August 1949, he was appointed Manager of Operations, which position he now holds.

Mr. Barefoot has been very active in the Association and served as its vice-president during the past year. He will take office at the regular monthly meeting held in Detroit on Jan. 25, 1952.

## Army-Trained Welders

The Army is training soldiers to be welders. Men with special manual aptitude from all Army areas of the country are brought to the Ordnance School at Aberdeen Proving Ground, Md., for a 10-week course in welding.

During the first week an instructor describes and demonstrates safety precautions and the use of equipment. Then for four weeks they work with oxyacetylene torches, welding and brazing cast iron, brazing steel and welding aluminum. Students learn by actual practice work on mild, medium and high-carbon steels.

In the succeeding four weeks instruction turns to arc welding. First, classes practice all-position arc work on mild steel; cutting, beveling, and eventually making butt and fillet welds. Then Ordnance Corps welding specialists teach the men to do carbon arc welding of copper, aluminum and cast iron.

The final week of the course is spent on actual arc cutting and welding of armor plate. The students are taught to distinguish between hard-faced and homogeneous armor. Next they work in the shop on pieces of armor used on the Aberdeen Proving Ground test firing ranges. Then, at the end of the week, they do simulated front line repair work on M-4 tanks.

Graduates, with 440 hr. of training and practical work, are sent to ordnance sections attached to armored and mechanized units throughout the army. In battle zones they may work from mobile welding and blacksmith trucks in positions just behind the front lines. When a damaged tank or self-propelled gun is pulled out of the line the welder crawls onto it, leaving his generator on the truck, and makes the necessary repairs.

The welding shop is run with an eye to efficiency as well as economy, using almost no new supplies other than gasoline, acetylene and oxygen.

## International Acetylene Association to Meet in Indianapolis, Mar. 31, Apr. 1 and 2, 1952

The 1952 Annual Convention of the International Acetylene Assn. will be held in Indianapolis, Mar. 31st, April 1st and 2nd. Latest developments in industrial and chemical applications of acetylene and the oxyacetylene process will be described by well-known engineers and technical experts in the industry. This meeting will mark the Association's 54 year of service to its members and to the public.

The Convention will open Monday, March 31st, at noon with a luncheon at the Hotel Claypool. Dean Clarence E. Mannion, College of Law, Notre Dame University, will be the guest speaker at the luncheon. The James Turner Morehead Medal, awarded annually by the Association in recognition of distinguished service to the oxyacetylene industry, will be presented. Following the luncheon two technical sessions will be held. A program has been prepared which will be of interest to students and faculty of schools and universities, as well as to industrial users of acetylene. Papers on acetylene chemistry and industrial applications of the oxyacetylene flame will be included. An evening session, to start at 7:30 P.M., is planned especially for students. This will include the showing of the motion picture, "The Oxyacetylene Flame—Master of Metals"; and a panel discussion on the subject "Employment Possibilities in Oxyacetylene Welding and Cutting."

On Tuesday, members and their guests, including students and faculty members from Purdue University and Rose Polytechnic Institute, will make an inspection trip of the Speedway Plant of Linde Air Products Co. The trip will show how acetylene cylinders are made, tested and charged with gas.

Wednesday morning the annual business meeting and election of officers will be held. A special closed session for the discussion of matters important to the industry will also be held on Wednesday morning.

All sessions of the Convention except the business meeting and closed industry session will be open to the public, and there will be no registration fee. Details of the program will be announced later.

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## Annual Meeting
## American Bureau of Shipping

The 90th Annual Meeting of the Board of Managers and Members of The American Bureau of Shipping was held on January 29th in the Bureau's board room, 45 Broad St., New York City.

Walter L. Green,* President, presided and expressed to more than 60 managers and members his appreciation of their attendance.

Mr. Green was re-elected President, and, in addition, was elected Chairman of the Board of Managers. Re-elected as Honorary Vice-Presidents were Joseph W. Powell and William D. Winter. David P. Brown* was elected as Senior Vice-President and will be Technical Manager of the Bureau. Jerome B. Crowley was also elected a Vice-President and will be in charge of Finance and Administration. Alfred Blum was elected Treasurer and Daniel L. Parry, Secretary. Kenneth D. Hull was re-elected Assistant Secretary-Treasurer. Harold M. Wick was appointed Assistant Vice-President and William H. Seelig, Assistant Secretary. Lewis C. Host,* who has been Assistant Chief Surveyor, was appointed Chief Surveyor.

In his remarks, Mr. Green said:

*Bureau Activity*

"On Jan. 1, 1952, 190 seagoing vessels of 2,413,561 gross tons and 19 Great Lakes vessels of 210,294 gross tons were under construction and/or under contract to be classed with the Bureau. In addition, there were 359 smaller miscellaneous type vessels aggregating 111,041 gross tons also contracted for to be built under the supervision of the surveyors to class with the Bureau. This new construction totals 568 vessels of 2,734,896 gross tons, which is a 170% increase over the totals of one year ago. On Jan. 1, 1951, contracts were in existence for the construction of 288 vessels of 1,055,840 gross tons to Bureau class.

"A total of 55 new vessels were completed to Bureau class in foreign shipyards during 1951, these aggregating 359,328 gross tons. This represents more than a 100% increase in tonnage over the 1950 results, when 33 new vessels of 159,037 gross tons were completed in foreign yards to Bureau class. Outstanding among these vessels is the *Giulio Cesare*, a twin screw passenger ship of 27,694 gross tons propelled by twin Diesels developing 25,000 brake horsepower. The majority of these vessels were constructed in Japan, but included three in Trieste, four in Italy, five in Spain, one in Canada and two in Holland. In addition considerable repair and alteration work on existing vessels was accomplished in foreign ports under Bureau supervision. An increase was experienced in the number of surveys conducted by the Bureau's foreign exclusive offices, as well as by nonexclusive surveyors.

"A total of 132 new vessels of 1,468,562 gross tons are now on order in foreign ports to be built to American Bureau of Shipping classification. A number of these will be finished in 1952 but others will not be completed until 1954 and 1955. Of these, 23 are under way in United Kingdom shipyards, three in France, three in Belgium, 21 in Germany, four in Canada, four in Mexico, five in Trieste, 13 in Italy, three in Spain, one in Brazil, nine in Holland, four in Pakistan and 39 in Japan. Exclusive Bureau surveyors are maintained at practically all of the shipyards at which these vessels are being built. These new vessels include tankers, bulk ore carriers, cargo ships, large passenger liners, one whale factory ship, a cable ship and barges.

*Technical Activities*

"The Technical Staff has been very active during the past year, there having been submitted for review and approval an abnormally large number of proposals for contemplated new construction and conversions, in addition to the increased amount of work resulting from the revival of activity in United States shipyards and the rapidly growing number of vessels contracted to be built to Bureau classification in other countries. The Bureau has continued to maintain members of the Technical Staff, assigned from the United States, in Japan and Europe and there have recently been returned to Italy two technically trained Italian surveyors who were given additional training in technical work in the New York office, with the result that through these representatives the Bureau is able to provide on-the-spot services to builders and designers, for reviews of their preliminary designs and for advice on the application of our Rules as the working plans are developed.

"As is usual, the Bureau staff had representatives on many outside committees during the past year and much time has been given to these activities. Among such committees are the Ship Structure Committee and subcommittee comprised of various governmental agencies and operating under a directive from the Secretary of the Treasury; the Technical and Research Committees of the Society of Naval Architects and Marine Engineers, and those of the American Society for Testing Materials; American Society of Mechanical Engineers; American Society of Refrigerating Engineers; American Institute of Electrical Engineers; National Fire Protection Association; AMERICAN WELDING SOCIETY and the National Safety Council.

"During the past year meetings of the several Bureau Technical Committees and Special Sub-Committees have been held for the purpose of reviewing the Rules of the Bureau and to consider modifications indicated as being desirable, based upon the service records of vessels and their machinery and equipment in class with the Bureau, and, also, to bring the Rules up to date with latest developments. As a result of these activities, several changes to the 1951 Rules have been adopted for inclusion in the 1952 edition, which will soon be available for distribution. Only very minor changes have been considered desirable to be made to the Rules relating to hull construction, materials and welding. In the Machinery Rules, the most important changes deal with stress concentrations in shafting. A new formula has been

* Members AWS.

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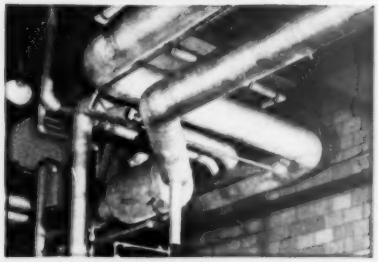
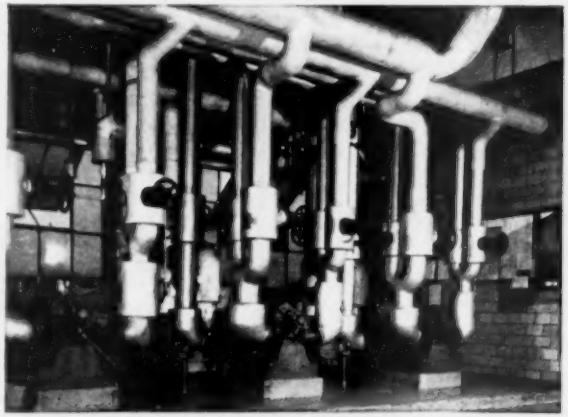
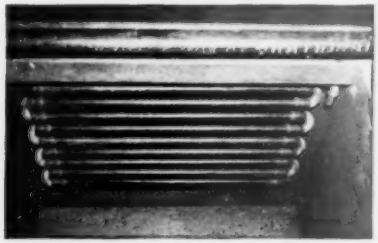
Such efficiency in production services has played a large part in the growth of Servel, Inc., makers of the famous Servel gas and electric refrigerators and a variety of other products.



With no flanges to work around, insulation was easily applied to welded steam lines. Joints will not leak, and insulation will last.



These 2½", 3", 6", and 8" lines for return water pumps and water booster pumps are fabricated with TUBE-TURN Welding Fittings. Close-fitting welded piping is compact and neat.



Steel blanks for cartridge cases are washed in this tank prior to forging operation. Time was saved in tank construction by fabricating heating coils with 1½" TUBE-TURN Welding Returns. Dimensional accuracy assured perfect line-up.

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added to take care of the special case of quill shafts, particularly in association with nodal drives for geared turbine installations. The requirements for propeller shafts have been rewritten to emphasize the necessity for reducing stress concentrations to a minimum in the design of propeller assemblies.

"Service records of the vessels which have been built since the adoption in 1947 of the present requirements for improving the notch toughness of hull steel plates and in which the improved steel has been used, as well as continued research activities on ship steel problems, have continued to support the action which was taken. There has been growing recognition of the Bureau specifications in steel producing and shipbuilding areas throughout the world, but in connection with some of the very large amount of foreign construction to Bureau classification, there have been some difficulties in obtaining literal adherence to our specifications on account of limitations in available materials and production capacities. George W. Place, our Principal Surveyor for Metallurgy, has just completed a trip to the United Kingdom and Europe, during which he discussed these problems with the Steel Manufacturers in England, Scotland, Germany, Holland, Belgium, France and Italy and we are pleased to report that as a result of these discussions many of the problems have been resolved, and we are assured that we will be able to obtain steel plates having the desirable properties aimed at in our specifications for the vessels building to our classification.

"With regard to the procedure for repairing shafting by welding, which was mentioned at last year's Annual Meeting, three of the major American repair yards have received Bureau approval to carry out this type of repair. Several yards in other parts of the world have expressed a desire to qualify, and we are presently attempting to work out a mutually acceptable method by which we will be able to do this and still retain the strict control and supervision which is so essentially a part of the procedure.

*United States Shipbuilding*

"The shipbuilding industry of the United States was greatly stimulated during 1951 through the awarding of many contracts, by private shipping interests and the Maritime Administration, for the construction of tankers and cargo ships. Orders are now in hand for the building of 97 merchant vessels of 1,252,525 gross tons and 1,750,000 deadweight tons. This is a record total for a peacetime period. Of these, 19 are designed for Great Lakes employment.

"Great Lakes shipyards are operating at peak capacity on new construction and a large variety of repair and alteration work on the existing fleet, much of which is designed to modernize the world's largest fleet of bulk carriers. Some of these vessels are being re-engined, re-boilered and lengthened in order to obtain greater carrying capacity, and, with the larger power plants being installed, will be able to accomplish an increased number of voyages in the relatively short operating period on the Lakes. Of interest is the fact that Diesel and geared turbine types of propelling machinery are being utilized in these conversions, instead of the steam reciprocating engines heretofore employed, while new boilers installed are designed for fuel oil instead of coal.

"The smaller shipyards located on the large rivers and in coastal areas are fully occupied with a large volume of merchant and military types of tonnage. These yards have also been affected by the shortage of steel for shipbuilding purposes.

"Only ten large merchant vessels were completed in United States shipyards during 1951, these totaling 147,569 gross tons and 183,032 deadweight tons. Not since 1936 has such a low level of annual production been seen. However, in 1952 there will be completed approximately 800,000 gross tons of merchant shipping, based on present schedules and if the needed amount of steel is made available. This will include some of the Maritime Administration's new high-speed "Mariner" class cargo vessels, Great Lakes bulk carriers and ferries and a number of the supersize oil tankers.

*Conclusion*

"We are now in a period of almost unprecedented peacetime activity in the shipping and shipbuilding industries, not only in the United States but throughout the world. A greater tonnage of merchant shipping is now being employed on the trade routes of the world than ever before


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**Robotron's ANSWER:** A new concept of Vernier Control, the Robotron "Cushioned-Power" Welding Timer pre-heats and prepares the welding material, welds and tempers according to specific needs, assuring welds of minimum surface indentation, maximum ductility and consistant uniformity.

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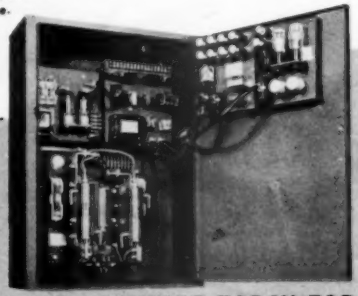

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experienced in a normal period. This in turn provides considerable maintenance work for ship repair yards and affiliated trades. Shipbuilding yards in the principal maritime nations of the world have a tremendous volume of business booked for the next three or four years, this now aggregating over 13,000,000 gross tons. This total would be even greater if more steel was made available, particularly in the United States where shipyards have been unable to consummate offered contracts. In addition, naval construction has experienced a considerable increase, together with large programs of reactivation and modernization.

"We must, however, keep in mind the fact that a large measure of the current activity in world shipping is a result of United States Government-sponsored relief, rehabilitation and military aid programs. Accordingly, we have to plan for the time when these programs have been completed and the volume of traffic drops to a normal world trade basis. While vessels of all nations are participating in this current heavy traffic from the United States, American flag vessels will particularly feel the contraction when it does come and competition with foreign flag vessels is intensified.

"With world shipbuilding at an all-time peak for peacetime, we can point to some recent developments as an indication of advancement in this field. For instance atomic power for ship propulsion will soon be an accomplished fact as a Navy submarine now under construction is to utilize this means of propulsion. Gas turbines, also, are being proved up for merchant ship propulsion, an oil tanker having been so equipped in 1951. Huge oil tankers of 40,000 tons deadweight became a reality last year with the ordering of two from a German shipyard, while four of 28,000 tons each will be built in Japan for United States interests. In the meantime, bulk ore carriers of 40,000 tons capacity have been designed and will no doubt be contracted for this year. Important innovations in cargo handling gear were seen on the new Maritime Administration cargo ship *Schuyler Otis Bland.*

"The largest merchant vessel ever built in the United States, the transatlantic passenger liner *United States,* will soon be competing for the trade on the North Atlantic. She has been preceded by the two fine Mediterranean luxury liners, *Independence* and *Constitution,* completed in 1951, and now in successful operation.

"With all this activity in shipping and shipbuilding, we are still living with maritime legislation which is badly in need of modernization. For instance, the Merchant Marine Act of 1936 is now fifteen years old and in all this period has never been brought up to date. While in the past three years Congressional committees have held public hearings on the subject, and accomplished much investigation, the so-called Long Range Shipping Bill is still in the pending category. It is vitally important that this shipping legislation be passed by the present Congress so that American ship owners can plan for the future."

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## World's Largest Steel Dome

Arc welding proved to be the answer to many complicated problems encountered in building the world's largest all-steel, shallow-type dome at the newly completed Jordan Marsh Store near Boston, Mass.

The huge dome, 225 ft. in diameter, is formed by 36 welded steel ribs—110 ft. long—which were fabricated and checked in the shops of the A. O. Wilson Structural Co., Cambridge, Mass.

A. O. Wilson used more than four tons of electrodes in construction of the dome. More than 400 tons of structural steel were used in the store, which is part of the new Framingham Shopping Center.

In spite of many technical problems connected with the job, the company, using welding wherever possible, was able to complete the erection of the steel structure for the dome in only 12 weeks.

Ring girders, 36-in deep and weighing 300 lb. per foot, around the base of the building support the huge steel ribs which meet in a 14-ft. hub. Since the 30-in. girders for the ribs could not be bent to match the contours of the dome, each girder had to be cut into five sections, beveled at the ends, and then welded together with 200-amp. welders.

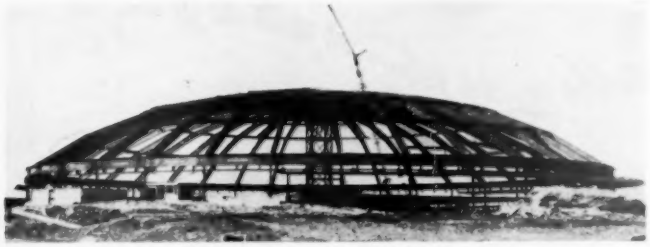
In order to raise the ribs and weld them to the hub at the center, a 60-ft. tower was erected. Since available room for the welding operators decreased toward the center of the hub, a plywood floor piece was fitted between the rings to support the welders who used three General Electric 300-amp. gasoline engine-driven welders.

Circular plates were welded around the hub above and below to complete this particular portion of the structure and 36 webs were welded to the hub to connect it to the ribs.

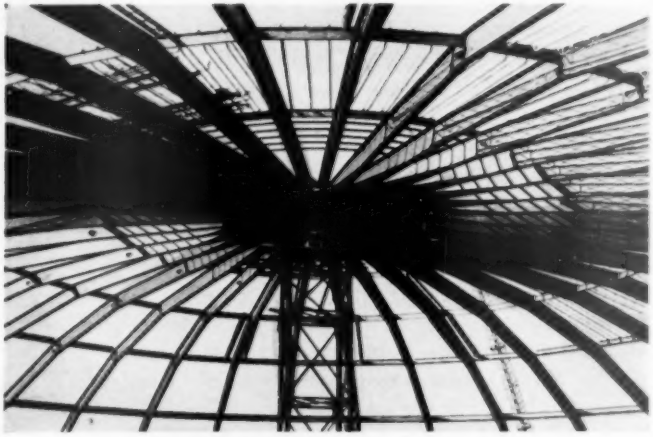
*Data and photos courtesy, General Electric Co.*

## Mullen Made Advisory Member

Henry A. Mullen, AWS Member Manager of the Resistance Welding Division of Ampco Metal, Inc., Milwaukee, Wis., has recently been appointed a member of the original Advisory Committee of the Resistance Welder Electrode Manufacturers Industry. This committee works in conjunction with the National Production Authority.



*Dome, largest of its kind, at the Jordan Marsh Store near Boston, Mass.*



*View showing hub of dome at Jordan Marsh Store*

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Location of flaws or defects in metals *before* or *after* any processing operation. You can locate porosity, pin holes or lack of fusion in welds; porosity or cracks in castings; cracks or laps in forgings; grinding cracks in machined parts; welding cracks in rolled parts; porosity and leaks in pressure vessels; heat-treating cracks; fatigue and stress cracks; and porosity or cracks in fired ceramics.

TURCO CHEMISTS, assigned the job of improving Dy-Chek in 1951, have now established penetrant inspection standards of efficiency and safety. With the partners, Dy-Chek—the completely flexible inspection process, and Chek-Spek—the high volume process, the widest range of your production inspection needs are served.

Since these two processes introduce physical chemistry into inspection methods, they must be (1) competently produced by a chemicals firm and (2) production supervised for uniformity by a long-established, highly trained staff of chemists. With either Dy-Chek or Chek-Spek, you can rest assured that Turco chemists have done their job well. Both processes are safe, accurate, reliable and inexpensive.

Is high-volume inspection critical to your production? Then ask about Chek-Spek... America's most inexpensive production-line inspection method. Used in conjunction with vapor degreasers, Chek-Spek permits accurate evaluation of an almost unlimited number of inspections per hour. Write on your own letterhead for complete information.

Re-working of defective parts is always accomplished economically and efficiently with use of Dy-Chek and Chek-Spek. Positive indication of extent, nature and exact location of flaws is still visibly apparent at the re-work location.

WRITE TO

DY-CHEK DEPARTMENT

**TURCO PRODUCTS, INC.**

6135 So. Central Ave.
Los Angeles 1, Calif.

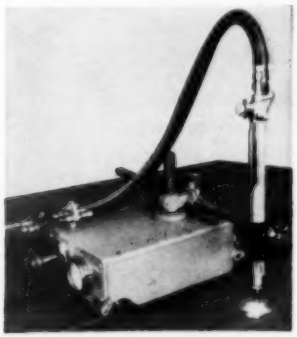
**LEADING INDUSTRIAL CHEMISTS FOR 25 YEARS**

# NEW PRODUCTS

## Portable Gas Cutting Machine

The Airco No. 20 Radiagraph has been announced by Air Reduction Sales Co., a division of Air Reduction Co., Inc.

Completely new in design, the No. 20 Radiagraph is the latest addition to Airco's famous line of gas-cutting machines. It is the first machine of its type specifically designed to be used as a travelling carriage for mounting such equipment as the Aircomatic® machine and the Heliweld Machine Holder in addition to fulfilling the requirements of a portable, motor-driven, straight track-guided cutting machine.



Portable, versatile and accurate, the No. 20 Radiagraph is built for lasting service with low maintenance. The transmission is a self-contained unit, the entire operating mechanism is mounted as a unit and all internal parts are easily accessible. All controls are conveniently located for easy operation. Any speed within the operating range (2–60 ipm) can be quickly and accurately set and maintained.

For further information about the new Airco No. 20 Radiagraph write to your nearest Airco office or to Air Reduction, 60 E. 42nd St., New York 17, N. Y.

## Contour Welding Speeded

Contour welds that formerly had to be made with manual apparatus can now be made semiautomatically with the new Heliarc HWM-1 welder. The new equipment retains all of the flexibility of manual operation and adds to it the obvious advantages of mechanized welding, such as uniformity of speed, arc length and weld deposit. High-quality welds can be made in sheet metal assemblies at speeds up to 100 in. per minute.

Developed by Linde Air Products Co., a division of Union Carbide and Carbon Corp., the Heliarc semiautomatic torch employs a filler rod which is fed automatically by electrically powered drive rolls through a flexible conduit into the tungsten arc of the torch. The driven filler rod not only serves as weld metal, but also provides a propelling force which moves the torch when the rod is kept in contact with the work. The welding operator merely strikes an arc, pulls a trigger to start the filler rod feeding, and steers the moving torch over the line of the weld.

Plain carbon steels and stainless steels in the thickness range from 0.020 to 0.125 in. are being welded with excellent results.

## Electrode Stabilizer

In the application of the Low-Hydrogen Welding Process, the Blueweld Lo-Hydrogen Electrode Stabilizer, Model 400 SE, a compactly designed unit with self-locking stacking arrangement, is used in individually controlled banks to meet varying production requirements. It is expertly engineered to stabilize the moisture content of low-hydrogen electrode coatings at the peak of their efficiency. Complete data are available from the manufacturer, Fred C. Archer, Inc., Milwaukee 3, Wis.

***Blueweld Stablizers stacked three high to provide capacity range from 400 to 500 lb.***

## Atomic Hydrogen Transformer Welder

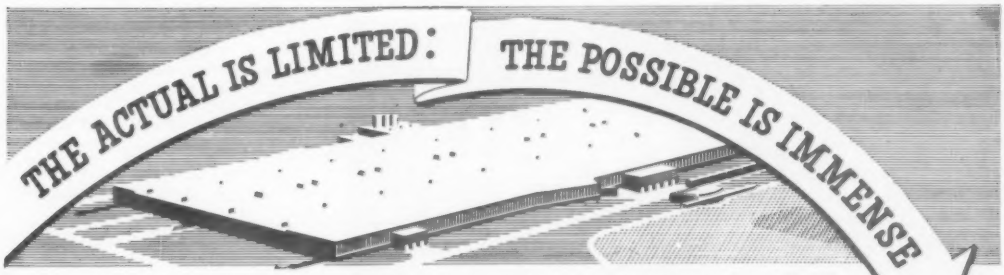
A redesign of its atomic-hydrogen transformer welder, incorporating a new hot-start circuit, silicone insulation and an extra-wide current range, has been announced by the Welding Dept. of the General Electric Co.

The new design, according to G-E engineers, not only results in a quicker starting, more durable, more versatile welder than the superseded model, but also permits a 17% reduction in price.

The extra-wide current range of 10 to 100 amp. allows the use of one machine on all applications. The range is divided into two sections, 10 to 35 amp., each extending the entire length of the indicator scale. This, the engineers say, allows precise current settings.

Other advantages of the new welder are noted as a longer coil life because of the silicone insulation, faster starting with the new hot-start circuit and a range switch to change from one current range to another without moving the welding cable.

In addition, the engineers said, the redesigned atomic-hydrogen welder retains many of the features of the former equipment. These were listed as power factor correction capacitors, portable "start-




NEW LINCOLN PLANT CREATED BY INCENTIVE-INSPIRED CO-ACTION IN DEVELOPING POSSIBILITIES IN PRODUCT

© LE Co. 1952

# PROPER DESIGN IN WELDED STEEL IMPROVES PRODUCT . . . cuts costs for Hanson-Van Winkle-Munning

THE examples show how one prominent manufacturer has improved the quality of his products while cutting costs by converting to welded steel design.

When designing for efficient welded steel construction, savings in initial material cost alone generally average 85% to 95%. This is because steel costs less per pound. And with steel's greater strength and rigidity, fewer pounds of metal are needed. In many cases, machining operations required for iron can be minimized or eliminated entirely.

Where product designs utilize the economies of welded steel, cost analyses show that:

**1.** Material costs for steel generally range from 5% to 15% as compared with castings.

**2.** Labor costs for fabricating steel are about 30% of initial casting purchase costs.

**3.** Welding costs average 50% of total labor costs for fabricating steel.

If your costs do not approximate these averages, your product designs should be reappraised. A Lincoln Welding Engineer will gladly point out what benefits of welded steel may have been overlooked.

**Inquire about the "Weldesign Training Course" for your engineers, designers and production men.**

**Fig. 3. Welded steel** *saves 30% cost . . . cuts weight 50%. Design is simpler . . . plain channel replaces complicated casting.*

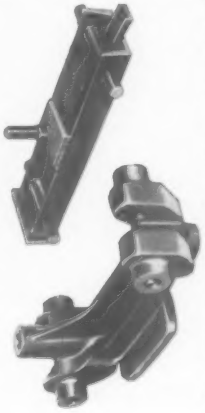


**Fig. 4. Stronger, more rugged machine part** *results when fabricated from steel strip and standard channel. Weight is cut from 3 lbs. to 2 lbs. 4 oz. Cost of this small part is 12% less.*

## ORIGINAL CONSTRUCTION

**Fig. 1. Machine bracket** *for* **Hanson-Van Winkle-Munning,** *Matawan, N.J. weighed 50% more than present steel design. Casting had to be left heavy for strength in hub and arm. Design made efficient use of cast iron by providing cored slots. Casting required milling and drilling.*

## PRESENT WELDED STEEL DESIGN

**Fig. 2. Finished weldment** *costs 25% less . . . eliminates former breakage experienced in casting. Steel hub, cut from bar stock and pre-drilled, is welded to simple formed steel arm in which holes are pre-punched.*

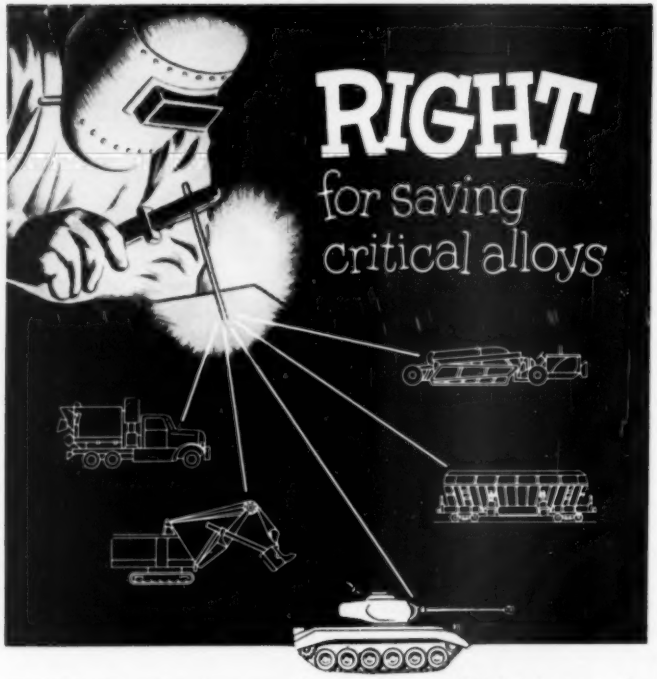
MORE SAVINGS

*Machine Design Sheets are available to designers and engineers. Write on your letterhead to Dept. 93,*

**THE LINCOLN ELECTRIC COMPANY**

**CLEVELAND 17, OHIO**

*The World's Largest Manufacturer of Arc Welding Equipment.*




**ARCOS Low Hydrogen Electrodes weld high tensile steel with savings in chromium and nickel**

| ARCOS LOW HYDROGEN ELECTRODES |
|---|
| Tensilend 70 |
| Tensilend 100 |
| Tensilend 120 |
| Manganend 1M |
| Manganend 2M |
| Nickend 2 |
| Chromend 1M |
| Chromend 2M |

Time and service have proved the effectiveness of welding high tensile steel with Low Hydrogen Electrodes. And today's heavy demands for freeing critical alloys make their use more timely than ever before.

First developed in 1942, Arcos Low Hydrogen Electrodes are subjected to the same rigid quality controls as applied to its Stainless. That's your assurance of uniform, high quality weld metal for use on armor and other commercial applications. It means sound, dependable welds on every job, every time. Arcos offers the most complete selection of Low Hydrogen Electrodes in the field.

**ARCOS CORPORATION** • 1500 South 50th St., Philadelphia 43, Penna.

Write for new booklet "The ABC's of Welding High Tensile Steels"

**WELD WITH ARCOS**

Specialists in Stainless, Low Hydrogen and Non-Ferrous Electrodes

stop" pushbutton, automatic gas shutoff and stepless current control.

The welder operates on 60 cycles, single-phase voltage, with a 75 amp. rating. It is 41½ in. high, 18¾ in. in diameter and weighs 350 lb. It sells for approximately $959.

### Nontoxic Dy/Chek Formula

Completion of a new, improved and nontoxic Dy/Chek formula was announced recently by President S. G. Thornbury, Turco Products, Inc., manufacturers of the dye penetrant inspection process.

"Interest in our metal inspection process has increased so substantially in the period that has elapsed since we assumed the manufacturing and distributing functions of Dy/Chek," Thornbury said, "that our large staff of research chemists has aimed at developing even more sensitive dye penetrant inspection materials. We are pleased to announce that this project has now been completed and that all Dy/Chek materials bearing the Turco label are of this nontoxic, nonhazardous formula."

The Dy/Chek method of inspection is basically a "hide and seek" process. After precleaning, a red dye is applied to the surface being inspected. After being allowed to dwell sufficiently long for it to "hide" in any flaw or defect—no matter how small—that extends to the surface, the dye is removed from the surface of the part being inspected. A white developer is then applied to the surface being inspected. This developer, as if by magic, "seeks" out the dye "hidden" in the flaw. As the developer dries, it pulls the "hidden" dye to the surface. The red dye thus bleeds into the white developer, marking with photographic clarity any defects—as well as their extent—that may be present.

Complete information and literature describing varied applications of Dy/Chek and how this revolutionary chemical process simplifies nondestructive testing may be obtained from Turco Products, Inc., Terminal Annex 2649, Los Angeles 54, Calif.

### Electrode for Cast Iron

To meet the double problem of a widely increasing use of welding in the maintenance, repair and salvage of cast-iron parts on the one hand and an extremely critical shortage of nickel on the other, a new nickel-free electrode for cast iron, EutecTrode 27, has been announced by Eutectic Welding Alloys Corp., Flushing, N. Y.

While this new rod does not replace nickel-bearing electrodes on all applications, it is said to offer an extremely high-tensile weld with a uniform amount of carbon in the deposit so that the deposited material is similar to a high-tensile, high-carbon steel, thereby increasing the tensile strength of the weld.

Complete details, technical specifications and data sheets on new EutecTrode 27 may be obtained by writing Eutectic Welding Alloys Corp., Dept. "P", 172nd St. and Northern Boulevard, Flushing, N. Y.

### Aluminum Rods

These new rods are identified as All-State X-438 Aluminum Rod meeting Government Specification QQ-R-566 Type 1 Class FS-RAL-43, and All-State X-28 Aluminum Rod meeting Government Specification QQ-R-56 Type 1 Class FS-RAL-2. The former is the cleanest of the high-purity 438 aluminum rods and the latter is the cleanest of the high-purity 28 aluminum rods. Their unusual cleanliness is due to extrusion manufacture to the exact diameter required. Drawing and the possibility of minute surface inclusions of the drawing compound are completely eliminated. These rods are designed for all work requiring 438 or 28 aluminum wire applied with inert gas, normal arc or torch. Standard diameters include 1/16, 3/32, 1/8, 3/16 and 1/4 in. Standard length is 36 in. and standard package is 50 lb. Both rods are also packaged in coil form, the standard package being 50 lb. Special lengths of rods can be obtained on order.

In addition to the above, both the 438 and the 28 alloys are available as drawn wire. Designations for the drawn wires are 438 and 28, respectively. The dropping of the X indicates that the sizing of the rods is not done solely by extrusion.

These new aluminum alloys are now available through All-State distributors everywhere.

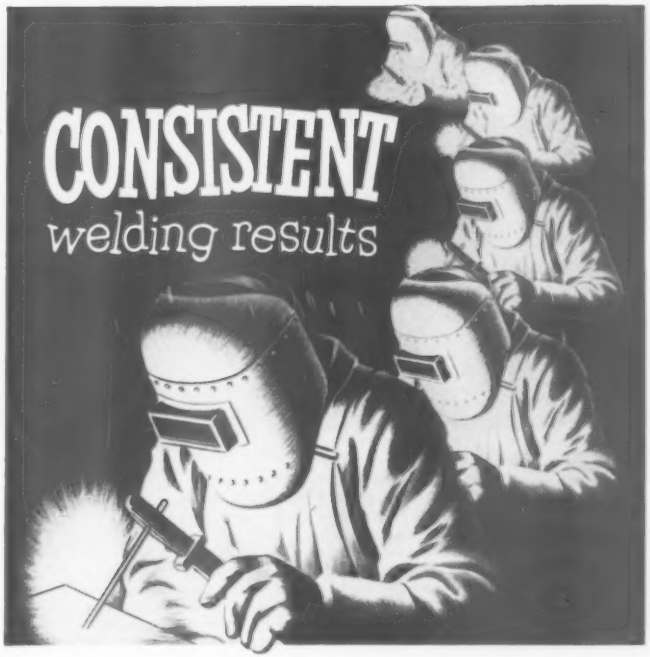
### Hopper Car Positioned

The Pandjiris Weldment Co. have designed and fabricated a quick acting welding positioner to automatically engage, raise and rotate a 70-ton hopper car to permit finish welding with the submerged-arc welding process.

The cars are tacked together before being rolled to the positioner on their own truck. After the car is properly located, it is clamped automatically by air cylinders which operate the outriggers on the positioner. Raising and rotating are accomplished by means of pushbuttons which synchronize the movements.

The entire operation of engaging the car, raising, removing the trucks, rotating 360 degrees, lowering and placing the car back on the trucks is accomplished in less than three minutes. Entry of the next car is made possible by raising the entire clamping fixture sufficiently high to clear the top of the car as it is rolled into position. There is no damage which occurs to the track since the car is raised clear before rotation begins.

In so far as it is known, this is the only unit, specifically designed to position cars without trucks which affords complete accessibility and eliminates obstructions to the welding process. By utilizing this positioner it was also possible to reduce a crew of eight men formerly required to turn the car to two men. Time required for the process was also reduced from hours to minutes. Approximately 300 ft. of welding is done in 17 min. by 10 manual welders and 12 semiautomatic submerged-arc welders. Production was increased approximately 50% over previous methods with one-third of the labor required.


**ARCOS Stainless Electrodes assure you quality weld metal—easily deposited—time after time**

You know the need today for producing sound, dependable welds on every job. It can mean savings in time, money and electrodes.

Benefits like these are yours with every box of Arcos Stainless Electrodes you receive. For each is backed by quality control tests more rigid than anywhere in the industry. That's why you can always count on Arcos for weld metal that is chemically, physically, and metallurgically of the highest type. It assures you of improved welding performance . . . more dependable results at lower weld costs.

**ARCOS CORPORATION** • 1500 South 50th St., Philadelphia 43, Penna.

**WELD WITH**

**ARCOS**

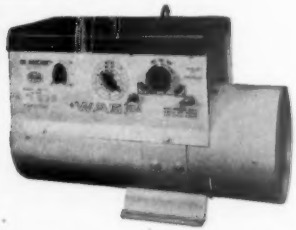
Specialists in Stainless, Low Hydrogen and Non-Ferrous Electrodes

Reports indicate the unit to be the safest positioning device. By eliminating dependency on overhead crane service it was possible to provide a mechanical pacesetter which demanded motions and efforts to keep up with the operation and permitted the calculation of production on a predetermined rate.

### D.-C. Arc Welders

The new Model GA "WASP" direct-current arc welders, available in 150 and 200 amp. sizes, have been announced by Air Reduction Sales Co., a division of Air Reduction Co., Inc.

Designed to further advance the efficient performance of the Wilson line, the volt ampere characteristics of these machines make them especially suited to d.-c. straight Polarity Heliwelding with Thor-Tung. Excellent commutation at all settings, plus the advantages of self-excitation and split-pole, cross-field design provide good operation at all current settings. Continuous overlap from each current range to the next provides a wide, unbroken range of welding current—30 to 250 on the 200 amp. welder and 20 to 185 on the 150-amp. machine.



These lightweight models provide easy portability when mounted on a two-wheeled carriage and require small floor space because of their compact construction.

### Production Stud Welder

New Standard Production Stud Welder is offered by the Stud Welding Division of KSM Products, Inc., Merchantville, N.J. Normal capacity of 3 to 6 welds per minute can be stepped up to 15 to 20 welds per minute with accessory equipment. The KSM Production Stud Welder is a heavy duty, adjustable unit designed to weld studs from $^1/_8$ in. to $^3/_4$ in. in diameter and from $^3/_4$ in. up in length. The welder operates on standard d.-c. welding current while control circuit operates on

Now...
ARC-DRIVE CONTROL
for D-C Rectifier Welder

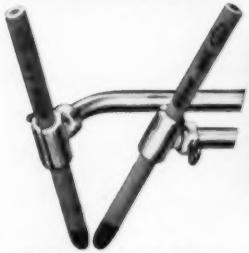
...Instantaneous response to arc-load changes
...Instantaneous recovery
...Reduced arc blow
...Completely adjustable by operator

Westinghouse RA Welders with new positive arc-drive control now prevent shorting when used on "drag" welding applications. In addition, they allow complete penetration on root passes of vertical and overhead welds. Arc-drive control is obtained by adjusting the ratio of short-circuit current to welding current without changing open-circuit voltage. Actual amount of arc-drive current can be varied by the operator.

For information on this improved RA Welder or other Westinghouse Welding Equipment, write Westinghouse Electric Corporation, Dept. DC 85, Welding Division, Buffalo, New York. J-21607-A-1

YOU CAN BE SURE...IF IT'S
Westinghouse
WELDING EQUIPMENT

BECKER
KEEN-ARC CARBONS

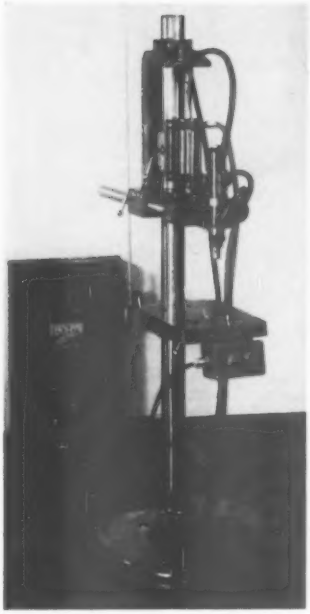


FOR CONSISTENTLY GOOD RESULTS

Designed to carry the high currents necessary for intense heat, BBB Keen-Arc Carbons produce a fine-grained weld of high tensile strength. They give a smooth, steady "flowing" flame which does not wander and which is concentrated at the desired focal point. Flame temperature is easily and accurately adjusted by merely changing the ampere input, and heavy copper coating permits gripping at extreme ends—eliminates frequent and periodic resetting.

A COMPLETE LINE OF CARBON WELDING SUPPLIES including carbon and graphite electrodes, carbon rods and plates, welding paste, etc. Write for catalog.

BECKER BROTHERS CARBON CO.
3450 South 52nd Ave. Cicero 50, Illinois



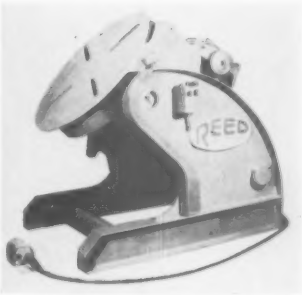
110-v., 60-cycle, a.-c. current. Control unit, complete with the stud welder, includes timers and air-pressure regulator.

The control unit is designed so that such accessories as indexing table, automatic vise, etc., can be easily plugged into outlets built into the control unit. A throat up to 18 in. is available with the stud welding head. The shut height of the head can be varied from zero inches up to 30 in. while the head itself can be rotated 360° around the main column. The stud welder, 18 x 30 x 16 in., weighs 210 lb. The control cabinet, 21½ x 16 x 28 in., weighs 125 lb. For more details write: Engineering Dept., Stud Welding Division, KSM Products, Inc., Merchantville, N. J.

### Welding Positioners

Illustrated is the new line of medium duty welding positioners recently announced by the Reed Engineering Company of Carthage, Mo. Two standard sizes are available, Model P-10R with a 1000 lb. capacity, and Model P-25R with a 2500 lb. capacity. The new design features a compact, three-in-one table tilting frame. This eliminates the indirect, inefficient power transmission trains used on older types of equipment, and reduces to a minimum backlash and lost motion in the table rotation system. Rotation speed can be varied through a 10 to 1 speed range by means of a conveniently located handwheel adjustment. Both Models are available with either hand or power tilting of the table through a 135-degree angle, and are equipped with tilt indicators.

"Optional equipment includes a rotating




welding current ground device mounted directly upon the table spindle, magnetic starters with limit switch protection for the tilting mechanism, various push-button or foot-controlled master switches, and a disengaging clutch in the table rotation system.

"Precision cut steel gears are used on both models to insure accurate, positive power transmission."

### New Gasoline Engine Driven Arc Welder

Hobart Brothers Co., Troy, Ohio, announces a new gasoline engine driven arc welder with the control panel conveniently mounted on the end of the unit at the generator end. The control panel has been moved from the side to the end of the unit

National
Carbide
IN THE RED DRUM
EFFICIENT
ECONOMICAL
DEPENDABLE

FOR WELDING and CUTTING
Use National Carbide in the Red Drum
Write us for information as to nearest available stock.
60 E. 42nd St. NATIONAL CARBIDE COMPANY New York 17, N.Y.
A Division of Air Reduction Co., Inc.

to centrally locate all controls for easier adjustment of the welding heat. On it are located the generator controls, meters, welding and ground cable terminals, polarity switch, ignition switch, starter button, oil pressure gage, and battery ammeter, as well as the receptacle for 1-kw. auxiliary power.

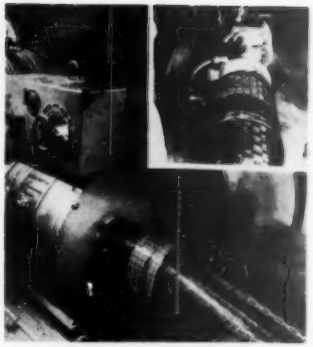
Control of the 1000 combinations of welding current and open circuit voltage is accomplished by the large wheel and Volt-Amp Adjuster (field rheostat) within the large wheel. The ten main steps or ranges are selected by means of a heavy copper switch, molded in bakelite, and is operated by the large hand wheel. The Volt-Amp. Adjuster provides 100 steps of fine adjustment in each of the ten main ranges.

This new gasoline engine driven welder is available stationary or mounted on a pneumatic tired four-wheel trailer. For more complete information, write The Hobart Brothers Co., Hobart Square, Troy, Ohio.

## New Truck Power Take-off

The new Tangen Power Drive is a power take-off unit which can readily be installed in standard trucks which have standard transmission units. The Tangen Power Drive is quickly installed as an integral part of the transmission and makes available 97% of the engine power for auxiliary power purposes. It can be easily removed from one transmission and installed in another.

Power is transmitted through the main drive gear in the transmission but the installation in no way affects the standard driving mechanism. Power is available whether the vehicle is in motion or stationary. Governor control permits operating the vehicle at desired rate of speed while maintaining rpm. required in the power drive shaft to give desired power output. It eliminates the need for a separate auxiliary engine for power applications.



The Tangen Power Drive is applied to trucks for operating arc welders, pumps, compressors, cement mixers, saws and other power tools. It is manufactured by Mobile Power Inc., Detroit, Mich.

## Machine Aids Tractor Roll Welding

Tractor rolls can be built up easily and economically on a welding machine built from a lathe and standard Unionmelt

LIL CHAMP
BOYS, THOSE CHAMPION C-30 ELECTRODES SAVE PLENTY ON DOWN-TIME. LOTS OF REPAIRS CAN BE MADE WITHOUT DISMANTLING — AND THE WEAR WE GET FROM BUILT-UP PARTS BEATS ANYTHING WE'VE EVER TRIED!
BLUE DEVIL CONSTRUCTION CO.
IT'S NO LONGER A PROBLEM TO WELD PULLEYS OR SHEAVES AND OBTAIN MUCH LONGER SERVICE LIFE WHEN WE USE CHAMPION C-30 ELECTRODES... THE WELD DEPOSIT IS TOUGH... POROSITY-FREE AND MACHINES FAR BETTER THAN A MILD STEEL WELD!
CHAMPION C-30 ELECTRODES ARE IDEAL FOR BUILDING UP SHAFTS AND OTHER MOVING CONVEYOR PARTS...
THE CHAMPION RIVET CO.
CLEVELAND, OHIO
East Chicago, Ind.
Write for descriptive literature

# RESISTANCE WELDING HIGH-TEMPERATURE ALLOYS?

## General Electric can help you in the proper selection of resistance welding control—single-phase and three-phase

Are you faced with resistance welding high-temperature, high-strength alloys or aluminum for defense production? Trying to decide between three-phase and single-phase welding control? Write for G-E literature that describes both types. We know, from experience in our own as well as customers' plants, that both are being used. Which *you* select will depend to a great extent on these factors:

**COMPARE SINGLE-PHASE AND THREE-PHASE**

| Single-phase | Three-phase |
|---|---|
| 1. Low initial cost | 1. Low KVA demand |
| 2. Low maintenance (easy) | 2. Balanced 3-phase load |
| 3. Simple to operate (few adjustments) | 3. High power factor |
| 4. Wide industry use | 4. Inherent slope control action |
| 5. Voltage and current regulators can be added later | |
| 6. Slope control can be added if necessary | |

General Electric has supplied, and used, both types to meet Army-Navy specifications, and our nearest local office can give you information based on experience with this equipment and with welding high-strength alloys. Before you buy—investigate. Write for bulletin GED-1512, or contact the nearest G-E sales office. *General Electric Company, Schenectady, N. Y.*

**Ask your resistance welding manufacturer, power supplier, or nearest General Electric office for a FREE showing of the sound and color movie, "This Is Resistance Welding." Describes various welding methods and processes. For production and engineering personnel training and refresher courses.**

**H. C. Wolfe, of the General Electric Electronics Laboratory Welding Section,** says, "Tests in our Laboratory and in other General Electric Welding Laboratories showed that single-phase a-c welding using Slope Control was as good as three-phase welding on aluminum. So, for Class A spot welding of aluminum, the use of our a-c machine with Slope Control certified to Military Specification MIL-W-6860 for .125-.125″ 52S$\frac{1}{4}$H aluminum has resulted in a considerable saving of money and time."

**Three-phase at Ryan Aeronautical Company** in San Diego controls several of the largest resistance welding machines in the country. With G-E 3-phase control exact heat settings can be obtained and duplicated later without variation. Uniform current is fed to the electrodes to produce the required heat with less momentary line load. Unidirectional spot-welding is also obtained—advantageous when welding sheets of different thicknesses.

GENERAL ELECTRIC

645-55

# this sword means Cancer RESEARCH

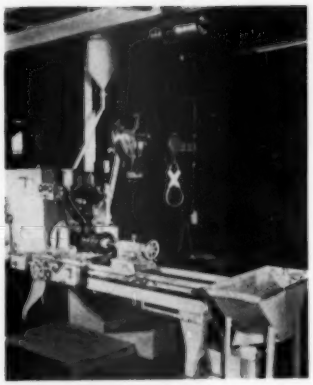
For millions cancer research is a race for life.

The American Cancer Society supports research in 100 institutions in 35 states . . . grants aid to 900 investigators . . . trains as fellows 78 young men and women.

However, some vital research has been retarded because of lack of funds . . . twice as many dollars could be used in 1952 under the sign of the cancer sword. Cancer Strikes One in Five. Your Dollars Strike Back.

*Mail Your Gift to "Cancer" Care of Your Local Postoffice*

**AMERICAN CANCER SOCIETY**

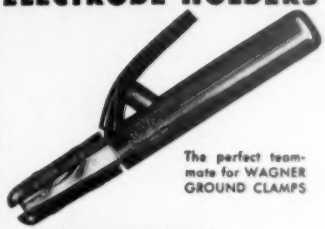



*Courtesy of Linde Air Products Co.*

***Fig. 1 A small-size tractor roll being built up by submerged-arc welding. An extension of the line center permits handling of larger rolls directly over the trough at right***

welding equipment, according to the J. D. Pittman Tractor Co. of Birmingham, Ala. Worn rolls are rotated beneath a submerged-arc welding head mounted on a movable saddle, as indicated in Fig. 1. Weld metal is evenly applied, speedily rebuilding the rolls and minimizing finishing operations. Troughs located beneath the work collect unused welding composition for re-use.


# WAGNER ELECTRODE HOLDERS



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| 163 | 313 | 600 | 1150 | 1700 |
| 175 | 325 | 650 | 1200 | 1750 |
| 188 | 338 | 700 | 1250 | 1800 |
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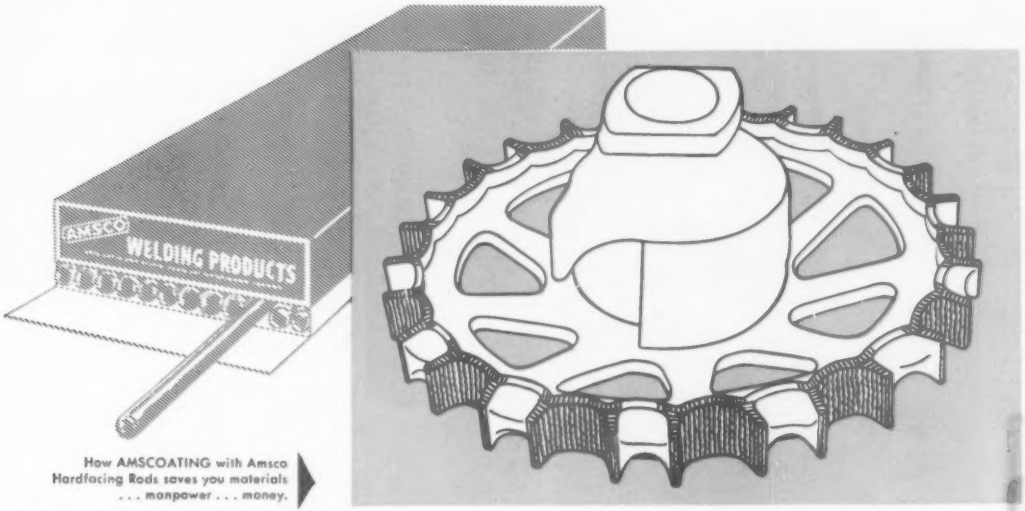


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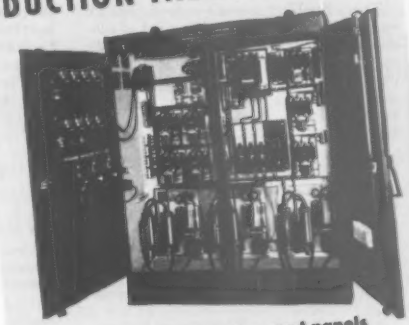
Engineering counsel on any electrical control problem is available through Square D field offices in all principal cities.



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# NEW LITERATURE

## Anti-Borax Fluxes

The Anti-Borax Compound Co., Fort Wayne, Ind., have issued a circular describing their various types of fluxes for cast iron, bronze, aluminum, steel, brass, copper, malleable iron, stainless steel and other applications. Copy available on request.

## Ampco Welding News

The 4th quarter *Ampco Welding News* has just been released by Ampco Metal, Inc., Milwaukee, Wis.

Included in this illustrated issue is an article discussing the welding technique used in fabricating sulphuric acid sludge tanks 24 ft. in diameter.

The uses of various resistance welding techniques for increased weld quality plus case histories of overlaying electric furnace trunion shafts and repairing cast-iron brackets with Ampco-Trode electrodes is included.

A free copy of this issue may be obtained by writing to Ampco Metal, Inc., 1745 S. 38th St., Milwaukee 46, Wis.

## Bibliography on Fatigue Articles in 1950

There has been issued by the American Society for Testing Materials a list of references to articles published in 1950 dealing with Fatigue. This bibliography was prepared by Committee E-9 on Fatigue through the work of a Survey Subcommittee headed by Prof. T. J. Dolan, University of Illinois, Urbana.

Brief abstracts of the articles have been included when these were readily available. The list is not exhaustive but may be sufficiently extensive to be of interest to those concerned with this field.

Both the nature and format of this list is experimental. References are generally so arranged that sheets can be readily cut apart for filing according to any desired plan.

Copies of the list of articles on Fatigue, comprising 28 duplicated pages, 8½ by 11 in., can be procured from A. S. T. M. Headquarters, 1916 Race St., Philadelphia 3, Pa., at $1.50 each.

## Alloy Welding Fittings Bulletin

The Key Co. of East St. Louis, Ill., developers and manufacturers of a new line of alloy steel welding fittings, has prepared a new bulletin on their "Key-Kast" products.

The new Key-Kast Alloy Welding Fittings are based on an entirely new design of greater wall thickness throughout for increased structural strength . . . and extra thickness at critical areas for greater allowance against erosion and corrosion. The advantages this new design principle offers for alloy piping systems are explained graphically in the new Bulletin, and the various alloys which will be available are also listed.

Copies of the new *Key-Kast Alloy Welding Fittings Bulletin* are available from the Key Co., East St. Louis, Ill.,

## "Economize with Castolin"

Because of growing metal shortages all over the world due to the universal rearmament program, R. D. Wasserman, L. Florin and G. M. Blanc have collaborated in the preparation of a book on the subject of the savings that the use of Eutectic's materials makes possible. This book, written in German, has just been published in Switzerland by the Technischen Informationsdienst Der Castolin Schweissmaterial AG, Lausanne. Price Fr. 3.75.

## Arc Welding

This book by Charles H. Zielke, is of magazine size, and consists of 64 pages copiously illustrated. It is based on the author's experience as a welder and as an instructor of welding. It is hoped that the practical approach he has attempted to use throughout the lessons will help to save time and effort on the student's part and eliminate unnecessary trial and error. The book is published by the Bruce Publishing Co., Milwaukee 1, Wis., and sells for 80 cents per copy.

## Welded Steel Building Construction

A new reprint containing two articles on welded steel building construction has been announced by Air Reduction Sales Co., a division of Air Reduction Co., Inc. Both articles originally appeared in the *Engineering News Record*.

"Welding Trims Steel from Heavy Trusses," by La Motte Grover and Gilbert D. Fish, discusses the design and fabrication of large all-welded trusses for Mt. Sinai Hospital, New York City. Other structural details also are covered and the advantages of all-welded construction are pointed out.

"Welding a 10-Story VA Hospital," by R. A. Phelps, discusses the design and erection of the all-welded, 10-story addition to the Minneapolis Veterans Hospital. A tabulation of steel requirements for welded vs. riveted construction shows a considerable saving in favor of welded construction. Labor and equipment costs also are included.

## Soldering Equipment Brochure

Just published is an 8-page brochure, *Mogul Soldering & Brazing Equipment*, offered by the Metallizing Company of America, 3520 W. Carroll Ave., Chicago. 24, Ill. Fully illustrated booklet describes the unique new "Mogul Soldering Gun" and shows applications of its use to production-line soldering and brazing.

## Manufacturing Processes

The Third Edition of *Manufacturing Processes*, by Myron L. Begeman, is written primarily for students and professionals engaged in production, industrial or tool engineering work. It gives the reader detailed information on all the important manufacturing processes and machines now available—where they can best be applied, their advantages and drawbacks, the tools required for each machine, etc.

The first half of the book is devoted to foundry practice, pattern work, plastic molding, powder metallurgy, hot and cold working of metals, heat treatment and welding. The second half covers measuring instruments, cutting tools, machines and their accessories.

The Third Edition has been completely revised to include the machines, processes and machine tools developed recently. The chapters on special casting methods, welding and allied processes, cold forming of metals and plastic molding have been completely rewritten. The new material includes sections on continuous casting of metal, Marforming, hydrodynamic forming, plastic molds, cold and stud welding, multistation transfer machines, tracer-controlled machines, jigs and fixtures, and many recent automatic and semiautomatic production machines.

Book has 608 pages, is priced at $6.00 and is published by John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, N. Y.

## Hard Facing Wall Chart

A new wall chart which details the proper hard-facing rod for the job has been released by the American Manganese Steel Division of the American Brake Shoe Co. The chart divides welding into basic operations, under which are listed the equipment parts to be Amscoated together with the recommended rod, available sizes and preferred method of application. A fuller description of the uses of each rod also appears on the chart. The result is an easily read, thorough and conveniently located reference guide.

The chart is 17 x 26 in. with tabs attached for easy hanging and has a lacquered surface to keep it readable under shop conditions. A wall chart may be obtained by writing, American Manganese Steel Div., Chicago Heights, Ill.

# A Statement by Anaconda on the Copper Situation

MANY users of copper have vital decisions to make . . . usually in connection with the present defense-induced shortages of copper and aluminum. This statement is an effort to remove the smoke screen surrounding the copper picture . . . to wipe away the confusion caused by too much talk supported by too few facts.

**Substitution poses problems** – Industry has been urged to substitute aluminum and other materials for copper. In some instances this may be logical and practicable. In many others it is difficult, if not impossible. But – before making *any* long-term decisions that may cost a great deal of money in engineering, new plant facilities or rescheduling of production operations – one should know the facts about the future of copper.

**New Anaconda projects** – The first major increase in copper production will come from Anaconda when the Greater Butte Project and the new Sulphide Plant at Chuquicamata, Chile, begin operations this spring. By 1953, these two projects should raise present levels of copper production by about 95,000 tons yearly.

Toward the close of 1953, Anaconda's new Yerington project in Nevada is expected to start producing at an annual rate of 30,000 tons. By then, Anaconda will be adding to the present yearly copper supply at the rate of about 125,000 tons.

**Other new projects** – During 1954-55 still other new projects in the U. S. and friendly foreign countries will further augment the increasing copper supply. All told, it is estimated that by 1955, not less than 450,000 tons of copper could be produced annually – over and above present production levels.

Accordingly, in 1955-56, domestic production plus imports could bring the U. S. copper supply to 1,800,000 tons yearly. This would represent an increase of about 20% over present levels. Based on historical comparisons, and barring a large-scale shooting war, this amount of copper could support a Federal Reserve Board Index of Industrial Production of 270, an increase of 24% over the present, and 45% above the first half of 1950.

• • •

These are the 'things to come' in copper. On the basis of the facts there is no necessity for considering long-range substitution of other materials for the red metal.

52320A

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## Accident Prevention

The *American Standard Manual of Accident Prevention in Construction, A10.1-1951*, has just been approved by the American Standards Association, 70 E. 45th St., New York 17, N. Y.

The standard presents, by illustrations, specifications and simplified text, the safe way of performing construction work and emphasizes the costly results of incorrect, unsafe practices.

The manual contains 43 chapters dealing with such subjects as sanitation, first aid, building demolition, electric welding, handling and storage of materials, excavation, explosives, pile driving, scaffolding, power saws, shafts, boilers, temporary electrical installations, fire hazards and prevention, occupational diseases, etc.

The Associated General Contractors of America developed the first edition of this manual 25 years ago, and they have revised it periodically to make sure that it reflects the latest industrial practices. All editions since 1938 have been submitted to ASA for approval as an American Standard. Approval as an American Standard certifies that a consensus of all parties-at-interest has been reached on the provisions of the standard.

## New X-ray Diffraction Booklet

A new 8-page booklet—*What is X-ray Diffraction*—is available from the Research & Control Instruments Div., North American Philips Co., Inc., 750 S. Fulton Ave., Mount Vernon, N. Y.

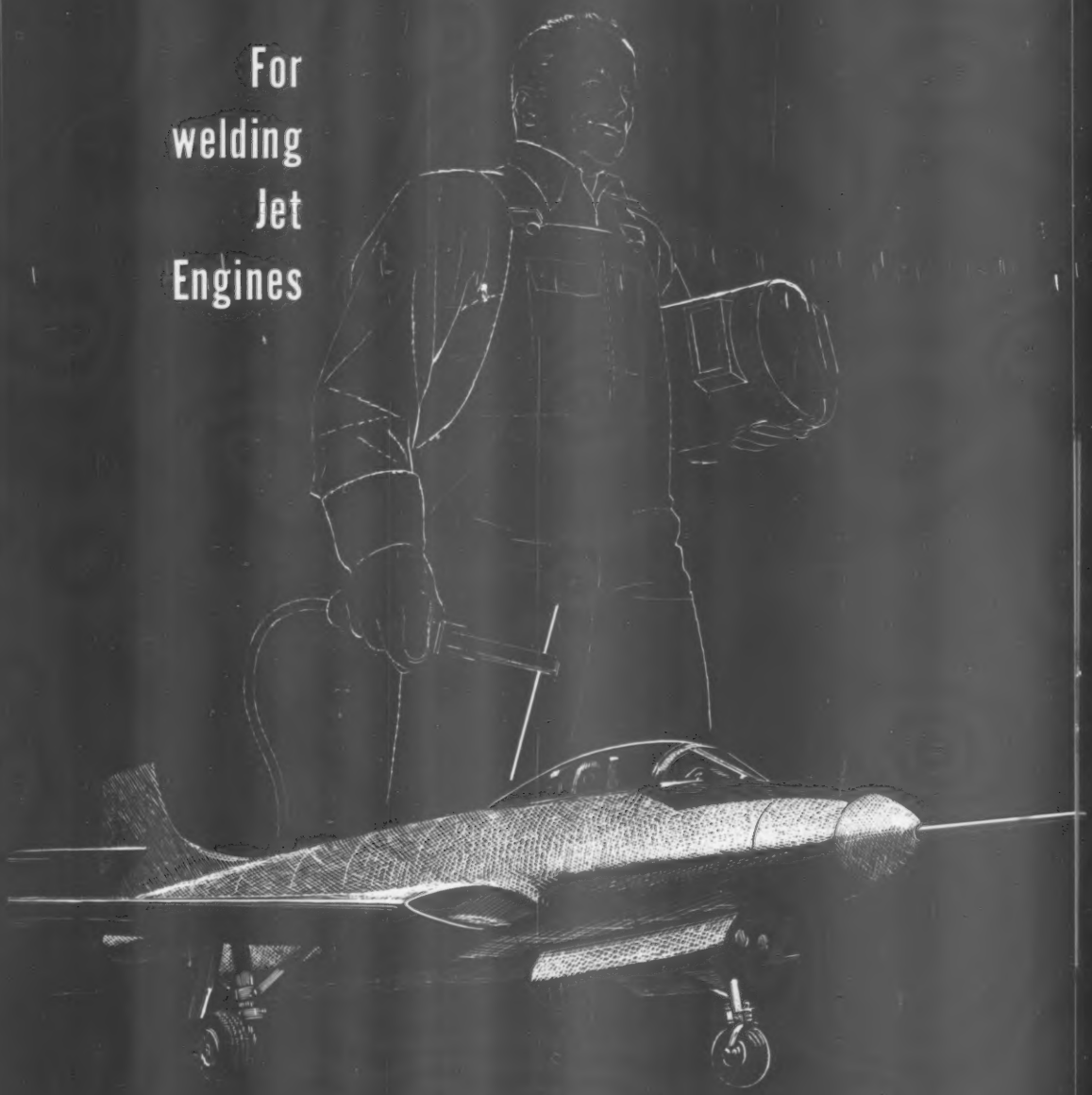
Booklet points out how this nondestructive analysis method is helping to speed the defense program in identifying components or raw materials to assure uniformity, in identifying unknown materials and constituents of mixtures, and in identifying impurities.

## B&W Tubular Products Division Offers Booklet on Tubing Failure in High Temperature and Pressure Service

The many factors affecting tube life in high-pressure, high-temperature applications are presented in a new 40-page illustrated booklet published by the Tubular Products Division of The Babcock & Wilcox Co. The booklet, *TR* 516, presents the results of a great number of investigations of failures of carbon steel, intermediate chromium-molybdenum alloy steel and stainless steel tubing in boilers, cracking stills, heaters and heat exchangers during service at elevated temperatures and pressures in the power, oil and chemical processing fields. It displays the history and experience behind the contemporary development of high-temperature tubing and will be of assistance to those in the field to obtain optimum failure-free service from their tubing installations.

Copies of the booklet are available free on request to the general offices of the division at Beaver Falls, Pa.

For welding Jet Engines



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Technical report on welding Jet Engines and handbook "The Welding of Stainless Steels"

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HERE'S a large 10½" diameter tube-mill gear with 120 teeth and an 11-inch face. A new one costs $2,148. This one was made better than new by "Bronze-Facing" it with wear-resistant Ampco-Trode 300 for only $530. Time required for the entire job — 42 hours.

You, too, can enjoy the savings in time and money made possible by "Bronze-Facing" with Ampco-Trode. Other advantages are: longer life and less down time. For instance, after 5 months' service in a cement mill, this gear showed little or no wear — thanks to the 300 Brinell tooth-surface hardness provided by Ampco-Trode 300.

In these days of shortages and long deliveries you'll find Ampco-Trode bronze electrodes a big help. Get a supply today from your Ampco distributor or write us.

Ampco Metal, Inc.
Milwaukee 46, Wisconsin
It's Production-Wise to Ampco-ize
Reg. U. S. Pat. Off., Ampco Metal, Inc.


## Hobart Arc Welding News

Volume VIII, No. 2, *Hobart Arc Welding News*, a 20-page booklet of interesting photographs and articles on welding from all over North America, is now available. Copies are mailed free of charge to anyone interested in arc welding.

Many of the articles contain time-and-money-saving applications. To get your copy, write the Hobart Brothers Co., Troy, Ohio.

## Permalatern Welding Alloys

The Permalatern Welding Alloys, Inc., Newtonia, N. Y., have issued a new 24-page welding-engineering guide of 40 pages giving the complete information on their various welding rods, covering almost every range of application. Copy available on request.

## Welding Couplings

Tube-Turns, Inc., Louisville 1, Ky., has issued an attractive four-page technical circular describing the new seal-arc welding coupling and its manner of application. Complete technical data given in the circular. Copy available on request.

## Three New Airomatic® Reprints

Three new reprints of articles on Airomatic welding have been announced by Air Reduction Sales Co., a division of Air Reduction Co., Inc. These articles originally appeared in THE WELDING JOURNAL and were given before the annual meeting of the American Welding Society.

"Airomatic Welding of Austenitic Stainless Steels" (Form ADR 77), a 16-page article by W. G. Reno, Jr., and E. R. Sohn, presents the results of an investigation of the mechanical properties and corrosion resistance of austenitic chromium-nickel grades of stainless steel weld metal and welded joints deposited with the inert-gas-shielded metal-arc process. Welding and testing procedures, tabular and graphic presentation of chemical analyses, mechanical properties and test results, and photomicrographs provide valuable basic data.

"Airomatic Welding Refinery Components and Pressure Vessels" (Form ADR 76), by Stephen A. Vuckovich describes procedures for welding stainless, stainless clad steel, low-alloy steel and copper-alloy pressure vessels with the inert-gas-shielded metal-arc process. The description of fabrication methods is supplemented with application photographs and sketches showing plate preparation.

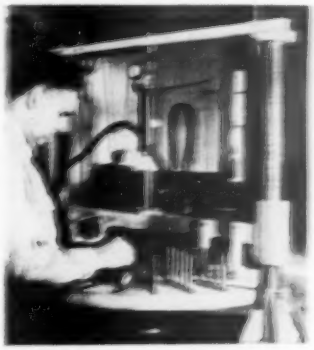
"Inert-Gas-Shielded Metal-Arc Welding of Magnesium" (Form ADR 75) by Paul Klein describes an investigation conducted to evaluate the application of the inert-gas-shielded metal-arc process to the welding of magnesium. Tabular and graphic test data, and photographs of specimen welds, accompany the discussion of arc characteristics, mechanical properties and weld soundness.

Copies of these reprints can be obtained from your local Airco office or from Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

## Handy & Harman Issues Silver Review

The demand for the industrial uses of silver continues to grow, according to the *Review of the Silver Factor for 1951*, issued by Handy & Harman, fabricators of precious metals.

In spite of a very sharp stepping up of demand for sterling by the silverware manufacturers, approximately 110,000,000 oz. of silver were consumed in the arts and industries in the United States, a drop of only 10,000,000 oz., the report says.



Courtesy of Handy & Harman

***Silver brazing of inverter tubes for shells. With a variable and manual induction heating coil set up, the operator places the prepared parts on the brazing studs and removes the finished parts***

The use of silver brazing alloys in industry has increased production in assembling parts with strong, leak-tight, ductile joints. The low flowing temperature and fast brazing action have caused manufacturing companies to turn to the alloys as a means of producing brazed parts in volume.

The review also points out that there is no apparent reason to fear that adequate supplies will not be available in the coming months, even if defense spending is stepped-up and the use of silver is substituted for scarce metals.

## Metallizing and Its Uses

Sixteen pages of up-to-the-minute information on this vitally important metal conserving industry. The Metallizer is published bi-monthly with the aim of providing maintenance men with the latest information and methods for saving metals and machines and increasing production by reclaiming worn parts through the use of metallizing.

Contains articles of lasting interest on the advantages of metallizing in the textile industry, metallizing worn valve stems, metal spraying with the Mogul Gun, and others. Photographs accompany each article. The Metallizing Co. of America, 3520 West Carroll Ave., Chicago 24, Ill.

# *abstracts of*
# CURRENT WELDING PATENTS

*prepared by V. L. Oldham*

***Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 25, D. C.***

2,580,502—Method and Apparatus for Welding the Longitudinal Seams of Barrel Blanks and the Like—James L. Anderson, Closter, N. J., assignor to Air Reduction Co., Inc., a corporation of New York.

This patent relates to apparatus for performing a method and to a method of welding longitudinal seams in tubular blanks of large diameter. The method includes shaping the edge portions of the metal blank along the seam to form a longitudinal corrugation and the blank is supported solely at points remote from the seam to minimize the conduction of heat from the metal. Thereafter, the seam is welded and the corrugation is progressively rolled out after the weld is completed and while the metal is still hot from the welding operation.

2,581,673—Continuous Method of Making Butt Weld Tubing—Frank J. Kennedy, Dormont, Pa., assignor to National Electric Products Corp., Pittsburgh, Pa., a corporation of Pennsylvania.

In this new welding method, butt-welded tubing is produced from continuously moving flat skelp and wherein the edges of the skelp are convexly rounded by edge rolling, and thereafter the flat skelp is cold reduced to uniform width and simultaneously the convexly rounded edges are flattened to produce a flow of the rim steel into the corners of the skelp by an edge rolling operation on the skelp in planes substantially at right angles to the faces of the skelp. The skelp is cold worked to a tubular blank with an open seam cleft and the edges of the seam are heated to a temperature of about 1200° F. by flames. Simultaneously the portion of the tubular blank opposite the seam cleft is heated to a temperature not in excess of 800° F. Subsequently the edges of the seam cleft are heated to a welding temperature as the tubular blank passes through roll passes and these edges are brought together while at welding temperatures.

2,582,268—Method of Welding—Anthony J. Nerad, Alplaus, N. Y., assignor to General Electric Co., a corporation of New York.

Nerad's welding method provides a protective flux layer over the welding area and includes applying a burning mixture of diborane and an oxygenous atmosphere to the portion of the metal to be welded.

2,582,860—Welding Shield—John W. Clerke, Little Falls, N. J.

An arc welding shield shutter and an arc circuit controlling apparatus are disclosed herein. An electrode holder is provided with a normally open switch which has one contact arranged for connection to one terminal of the source of welding current and the other contact is connected to the other terminal, and a solenoid having a substantial time lag is in series with the second connection of the switch. Additional means are provided and are operated by the solenoid for moving the shield shutter into eye-protecting position when the contacts are brought together.

2,583,163—Alloying Process in Bonding of Metals—Rene D. Wasserman, New York, N. Y.

This welding or bonding process includes supplying first a relatively thin layer of a bonding material to the surface of the base metal and allowing at least one ingredient of the bonding metal to alloy itself with at least one ingredient of the base member. This provides an intermediate alloy stratum which then has melted thereonto a weld metal to bond such weld metal to the base metal. Thereafter, a different weld metal is applied to the layer of weld metal with such different weld metal having a higher melting point than the first weld metal layer.

2,583,362—Welding Shaft and the Like—William C. Dunn, Cleveland, Ohio, assignor to The Ohio Crankshaft Co., Cleveland, Ohio, a corporation of Ohio.

Dunn's patented apparatus is for butt welding objects wherein the objects are held with their surfaces in confronting spaced relation. An induction coil is movable into and out of the space between the confronting surfaces of the objects and, when energized by a high-frequency alternating current, it inductively heats such surfaces to welding temperature. Means are provided to move such induction coil from between such surfaces so that they can be brought into abutting relationship.

2,583,455—Method and Apparatus for Welding Aluminum and Its Alloys—Lionel Bray Wilson, Prescot, England, assignor to Williams & Watson Ltd., Liverpool, England, a British company.

This is a method of resistance welding aluminum or aluminum containing articles of relatively small cross-sectional area. It includes flashing the ends of articles and bringing the ends into intimate contact under light pressure while welding current is provided. The ends of the articles are maintained in intimate contact until they are raised to the melting point and the ends are continued in intimate contact until the metal melts sufficiently to break the welding current circuit. Immediately the ends of the articles are brought together under heavy pressure, the welding current being off during the final consolidation of the joint.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It signifies that you contribute to the advancement and perfection of welding through active participation in the American Welding Society. Emblems available through A.W.S., 33 W. 39th St., N. Y. C., at cost.

# LIST OF NEW MEMBERS

*Effective January 1, 1952*

**ANTHONY WAYNE**

Clark, Delbert (B)
Evertts, Gerald B. (B)
Helvie, Thomas (B)

**CHATTANOOGA**

Reich, Harry F. (B)

**CHICAGO**

Eriksen, Reidar (C)
Holby, Eric (B)
Simpson, Roy W. (B)

**CLEVELAND**

Erdman, Harvey C. (B)
Fennema, R. G. (B)
Harlow, M. L. (B)
Herron, James (B)
Johnson, Glenn (C)
Luxeuil, Raymond (B)
Mc Laughlin, Barry F. (B)
Mehno, William (B)
Mentel, R. A. (C)
Sooy E. Chester (B)
Tullis, Robert (B)
Tulloch, James (C)

**COLORADO**

Allbee, James E. (C)
Binkley, William D. (C)
Brown, Arthur L. (C)
Cook, W. P. (C)
Heinschel, E. L. (C)
Percy, John N. (B)
Warner, Avery (C)

**COLUMBUS**

Japikse, Bertrand (B)
Leaf, Allen M. (D)
Tavener, William O. (C)

**DETROIT**

Cronin, Robert E. (B)
Dietrich, Joseph C. (C)
Kelly, F. J. (B)
Reagan, Walland W. (B)
Riley, Arthur Dale (C)
Rothweiler, Alfred (B)
Stirk, George H. (C)

**HOUSTON**

Allen, Horace C. (B)
Blackburn, M. M. (C)
Gainey, Jack F. (C)
Howell, Holland (B)
Meeks, William C. (B)
Wilson, D. E. (B)

**KANSAS CITY**

Corriston, R. W. (C)

**LONG BEACH**

Clarke, C. Lowell (C)
Craig, James P. (C)
Munselle, A. C. (C)

**LOS ANGELES**

Beauclair, Louis J. (B)
Haller, Laurence B. (C)

**MARYLAND**

Freeman, G. L., Jr. (C)
Lynch, Dunstan, W. P. (C)
McPherson, Thomas Calvin (C)

**MILWAUKEE**

Park, Rodney (C)
Spoor, John W. (B)
Zimmermann, Michael W. (B)

**NEW JERSEY**

Cunningham, J. Warden (B)
Gilson, Hiram B. (B)
Protus, Joseph (B)
Wolf, Raymond A. (C)

**NEW ORLEANS**

Hart, Jesse A (A).

**NEW YORK**

Bullock, W. E. (B)
Johnson Arvid L. (B)
Patchen, Mortimer (B)

**NIAGARA FRONTIER**

Cascio, Louis J. (B)
Holcombe, A. Laurance (B)
Noble, H. J. (C)
Semmler, Arthur O. (C)

**NORTHWEST**

Falconer, Sid (B)
Riebeth, Thomas V. (C)
Smith, C. M. (B)
Zoesch, Arnold Bernard (C)

**NORTHWESTERN PA.**

Wilson, Albert H., Jr. (B)

**OKLAHOMA CITY**

Hurley, Hugh H. (B)
McMillan, Louis (C)

**PASCAGOULA**

Shepherd, Arthur H. (C)

**PHILADELPHIA**

Brinkman, Harry (B)
Braun, Morton A. (B)
Busel, Joseph (B)
Hill, Ralph D. (B)
Michetti, Albert L. (B)
Noden, Albert L. (B)
Whittington, Raymond C. (B)

**PITTSBURGH**

Coulter, H. Frank (B)
Forbes, John E. (B)
Nelson, Frederick G. (C)
Ziegler, Kenneth H. (B)

**ROCHESTER**

Allen, Walter J., Jr. (C)
Comisso, Francis T. (C)
Kirsh, P. L. (B)

**SAGINAW VALLEY**

Bohlen, Richard C. (D)
Lamb, A. U. (C)
Makulinski, Irving S. (C)
Schanstra, Caroles (D)
Thompson, Ralph H. (B)

**ST. LOUIS**

Mackley, Marvin C. (C)

**SALT LAKE CITY**

Clayton, Elmo (C)
Davis, Halbert Dean (D)
Thompson, Ortize, N., Jr. (D)

**SAN FRANCISCO**

Stephens, Philip B. (B)

**SUSQUEHANNA VALLEY**

Kalanick, John (C)
Matukonis, Frank (C)

**SYRACUSE**

Davidson, W. M. (B)

**TOLEDO**

Pohl, Norman C. (C)

**TRI-STATE**

Rush, Hugh M., Lt. (C)

**WESTERN MICHIGAN**

Adams, John Quincy (B)
Enbody, Orval G. (C)

**WICHITA**

Stucky, Menno (C)

**YORK-CENTRAL PA.**

Blodgett, F. L. (B)
Hohman, George M. (B)

**NOT IN SECTIONS**

Belanger, Pierre (C)
Colvin, Robert Glen (B)
Fletcher, John Williamson (B)
Schulz, Herbert (B)

## *Members Reclassified*

***During the month of January***

**DETROIT**

Beronius, Harry (B to A)

**PHILADELPHIA**

Mehl, Walter (B to A)

**ST. LOUIS**

Scheiman, James (D to C)

**NOT IN SECTIONS**

Topractsoglou, Anastasios A. (D to B)

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### *Ramsay Moon, Obituary*

(*Continued from page 246*)

Development to the Ministry of Supply (England), in forming the Advisory Service on Welding, of which body he later became Director.

In 1942, again with the help of Dr. Gough, he established a training school at Portobello, near Edinburgh. This school was designed to give drawing office and works personnel a short practical and theoretical training in welding.

During his period of office as Director of the British Welding Research Assn., Mr. Moon advocated a scheme of expansion which culminated in the purchase and equipment of the Research Station at Abington, near Cambridge.

Mr. Moon left the services of the Welding Research Assn. in September 1947, to establish a business as a Consulting Engineer in Canada, but returned to Australia early in 1950. It was on a voyage from here to England that he came to his untimely end.

Shortly after his arrival in Canada, Mr. Moon took an active interest in the work of the Structural Steel Committee of the (American) Welding Research Council.

During his time in England he published numerous articles in the technical journals and his book *The Design of Welded Steel Structures*, published by Pitman in 1939, was rewritten and published again in 1948.

He was a Member of the Institute of Engineers of Australia, and a Member of the Institution of Structural Engineers of Great Britain.

You can weld in very close quarters with this 200-amp torch by reducing the extension cap from 3¾" to ¾".

# G-E Inert-Arc Torches and Tungsten Reduce Costs, Improve Weld Quality

## VERSATILE 200-AMP INERT-ARC TORCH FEATURES EASY, ECONOMICAL OPERATION

Efficient use of gas and ease of operation assure you high-quality welds at lowest cost with the 200-amp G-E Inert-Arc torch.

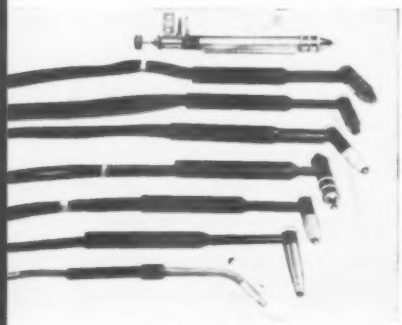
Whatever your application—stainless, aluminum, fernico, Inconel* or any of the hard-to-weld metals—you'll find this light-weight, easy-to-use torch is cooler operating, lasts longer, and assures maximum tungsten life.

The length of tungsten can be adjusted in a matter of seconds by means of the fingertip control knob. Furthermore, you can reduce stub-end loss to only 1⅛ inches.

When damage to the nozzle occurs, the new nozzle design permits refinishing many times without affecting the orifice size.

Available in a continuous rating of 200 amps, this torch comes equipped with 20-foot cables, enabling you to cover over 1000 square feet of floor area. For cost savings and increased production on your toughest Inert-Arc jobs, try the G-E 200-amp torch!

* Reg. trademark, International Nickel Co.



You can weld better and faster with one of the eight types of G-E Inert-Arc torches rated 15-800 amps, air- or water-cooled.

### G-E TUNGSTEN IS 99.9% PURE, GIVES STABLE ARC, MAXIMUM LIFE

For neat-appearing welds of highest quality, try G-E tungsten on your next Inert-Arc welding job.

Because G-E tungsten is 99.9% pure and has an extremely high melting point, you get a stable arc, clean, uncontaminated welds and maximum tungsten life. G-E tungsten is available in diameters from .040 to ½ inch, and in lengths from 3 to 24 inches.

### HI-THORIA GIVES 10 TIMES NORMAL LIFE, WON'T "BALL UP"

Cut welding costs and improve weld quality on your straight-polarity DC Inert-Arc welding by using Hi-Thoria tungsten. Hi-Thoria won't "ball up" on the end. Hi-Thoria resists contamination, thus reducing operator idle time. Hi-Thoria also provides a very stable arc over a wide current range, and actually lasts more than ten times as long as ordinary tungsten!

Hi-Thoria tungsten (right) resists contamination and balling up usually experienced with ordinary tungsten on DC.

**See your nearest G-E Welding Distributor** for a complete line of water- and air-cooled Inert-Arc torches, plain and Hi-Thoria tungsten. He also carries welders, electrodes and accessories to meet all your welding needs. You can find his name by looking for General Electric under "Welding Equipment" in the yellow pages of your telephone directory.

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712-13

# SECTION NEWS AND EVENTS

***as relayed to C. M. O'Leary***

### Welding Aluminum Alloys

**Baltimore, Md.**—A record attendance of 112 members was present at the January 20th meeting of the *Maryland* Section to hear G. O. Hoglund, AWS, of the Aluminum Company of America, deliver an excellent talk on "The Welding of Aluminum Alloys." This talk illustrated with slides described the progress that has been made in the welding of aluminum alloys during the past few years. In addition to explaining the metallurgical effects of welding on aluminum alloys and the effects of various alloying elements on the physical characteristics of the material, Mr. Hoglund gave many practical applications of the different aluminum welding procedures. Inert gas arc methods have made possible many new welding applications for aluminum and the mechanization of the inert gas arc process has resulted in a greatly increased use of this procedure for production work. The recently developed cold welding of aluminum was described together with a discussion of its limitations. The brazing of aluminum has grown to be a widely used procedure and has many applications in manufacturing plants today. Following his talk Mr. Hoglund showed an excellent motion picture "This Is Aluminum." This film produced in color for the Aluminum Company of America showed the complete story of the production and fabrication of aluminum from the mining of the raw bauxite to the production of the aluminum base metal and final fabrication into the finished products.

Prior to the technical session, E. T. Clayton, President of the Tainton Co., Baltimore, Md., gave an interesting coffee talk of a trip through Kruger National Park in South Africa. His talk was illustrated with color movies which he took of the wild animals.

The Educational Lecture Series sponsored by the Maryland Section at Johns Hopkins University has brought forth a great deal of interest from those interested in welding. A record registration of approximately 300 signed for the series of six lectures. The first lecture, "Welding Processes," was given by John Cumberland and the second "Welding Procedures" by Bela Ronay, both members of the Maryland Section.

### Battle of the Cities

**Bethlehem, Pa.**—The January 7th meeting of the *Lehigh Valley* Section was held at the Hotel Bethlehem, this city. A very interesting question and answer program in which teams of AWS members from Allentown, Bethlehem and Easton competed with each other in answering questions relating to welding design, metallurgy and fabrication. The team from Allentown was declared the winner after a tough "Battle of the Cities." The program was received enthusiastically by approximately fifty members and guests.

### Machine Tool Bases

**Bridgeport, Conn.**—Joseph McCashron, President of the Boiler Repair and Welding Co., this city, was the speaker at the technical meeting of the *Bridgeport* Section held on Thursday, January 17th, at Rapp's Restaurant, Shelton, Conn.

The coffee speaker was George Chaplin, Staff Assistant of American Telephone and Telegraph, New Haven. Mr. Chaplin gave an excellent account of the advantages of the Dale Carnegie Course.

Mr. McCashron presented an excellent, nontechnical talk on "Design and Fabrication of Machine Tool Bases," which was of particular interest to the engineer and production department personnel. His remarks were illustrated with slides.

### Design for Welding

**Buffalo, N. Y.**—John Mikulak, AWS, Worthington Pump & Machinery Corp., Harrison, N. J., was the speaker at the January 24th meeting of the *Niagara Frontier* Section held at the Sheraton Hotel, this city. Mr. Mikulak is a graduate of the University of Minnesota. He became associated with welding in 1938. He was associated with the Electric Machinery Corp. as assistant to Mechanical Engineer in charge of all welding operations. He was Chief Engineer of Welded Products Division and Senior Research Engineer at American Car and Foundry Co. At present he is Assistant to the Vice-President in charge of manufacturing at Worthington Pump. His talk on "Product Design for Welding" and his slides stressed redesign of steel castings so that they can be made up of small components welded together in place of the usual one-piece integral castings which require extensive coring.

Mr. Mikulak's talk and slides were of much interest to nearly everyone present, which included seven persons from Toronto, Canada—100 miles away. Also present was a resident of England on a visit to Toronto, guest of Neil McCarthy, AWS, Welding Engineer with John Inglis Co. Ltd., Toronto.

Fifty-seven members and guests attended dinner and 88 were present at the meeting.

### Stainless Steel Weldments

**Cleveland, Ohio.**—The *Cleveland* Section had a peak attendance at its regular meeting held on Wednesday, January 9th. One hundred twenty-eight members and guests were served dinner in the Mather Room of the Hotel Allerton. A few who could not make the dinner came later to the meeting.

Education and Plant Visitation Chairman J. S. McKeighan announced the next plant inspection will be made on Wednesday, March 26th, at 8:00 P.M., to the Euclid Road Machinery plant recently completed on St. Clair Ave. No reservations are necessary to make this trip.

The Annual Symposium of the Cleveland Section will be held this year on the second Friday in May, which is May 9th.

Coffee speaker at the January 9th meeting was Otto Rose, AWS, Executive Vice-President of the Colonial Iron Works Co. Mr. Rose spoke on the subject, "Europe—12 Years Later." Mr. Rose's native city is Vienna, Austria, where he was born and educated, receiving his civil engineering degree from the Engineering College of Vienna in 1934. He practiced engineering in Vienna until 1938, at which time he was interned in the Nazi concentration camps at Dachau and Buchenwald for seven months. After being released, he and his family left on Jan. 14, 1939, to make Cleveland their home. Mr. Rose spoke to the Cleveland Section in 1944 of his 1938 experiences.

In the summer of 1952, Mr. and Mrs. Rose returned to Vienna for a visit on the occasion of their wedding anniversary. They took two reels of colored moving pictures, showing the beauties of Paris and the bomb damage of Vienna as well as scenes in London. These pictures were shown at the meeting with commentaries by Mr. Rose.

The technical session got under way under the chairmanship of Bob Henry. E. R. McClung, AWS, and Leonard Pompa, AWS, presented a joint paper on "Fabrication of Stainless Steel Weldments."

Both speakers are associated with Lukenweld Division of Lukens Steel Corp. Mr. McClung as Superintendent and Mr. Pompa as Executive Engineer in charge of weldments and machinery. Mr. McClung was the 1947–48 Philadelphia Section Chairman. Mr. Pompa was the recipient of the 1947 Lincoln Foundation "Design for Progress" First Divisional Railwoad award of $3200.

The paper presented on this occasion had considerable local interest inasmuch as the discussion dealt largely with Diesel engine weldments produced in the large Cleveland plant of General Motors Cleveland Diesel Engine Div.

The discussion brought out the difference in metallurgical behavior of stainless and carbon steels in the welding processes, especially in the setting up of stresses and the necessity of stress relieving. The speakers stated that heat treatment for

stress relieving of stainless would require much higher temperatures but because of the nature of the metal and the small amount of stress in the weld area no stress relieving of stainless is necessary and it is not the practice to stress relieve stainless weldments.

Mr. McClung delivered the talk and Mr. Pompa answered the questions.

This was "Executive Night," a new idea with the Cleveland Section. Executives of member firms were well represented and it was the idea to show, firsthand, the good derived by their subordinates from Cleveland Section meetings. This, no doubt, will become a regular feature.

### Inspection Trip

**Dayton, Ohio.**—The trip to United Welding Co. in Middletown, Ohio on Nov. 13, 1951, was marred by a violent storm that afternoon and evening. As a result about half of the group that had signed up to make the trip actually got to the plant. An indication of the storm was that several power outages occurred during the trip.

Excellent examples of heavy weldments going into the railroad and construction machinery were seen. Practice in cutting, positioning and automatic welding were noted.

### Welding Design

**Dayton, Ohio.**—Professor R. S. Green, AWS, Chairman, Dept. of Welding Engineering, Ohio State University, gave a very interesting and informative talk on "Welding Designs" at the January 8th meeting of the *Dayton* Section.

Professor Green outlined the whys of typical joint designs and the allowable stress values of welded joints. This was information new to most of the members attending the meeting.

The versatility of welding methods was demonstrated by showing the various ways a typical weldment could be made. Much design is dependent on the tooling and methods currently used in the shop that is making the weldment. It is important that the designer know and take this into consideration.

Professor Green also outlined a typical proportional design from a casting, that is just making the weldment as strong as the casting it is replacing. This type of design appears quite often, where we know a piece is working satisfactorily and no attempt is made to thoroughly analyze how strong it should be.

Professor Green's talk immediately followed the AWS film strip on Applied Welding Engineering and tied into the design aspect of it very well.

Professor Green received the degrees of Bachelor of Science in Civil Engineering in 1936 and Master of Science in Engineering in 1942; both from Purdue University.

Professor Green is currently consultant to the National Certified Pipe Welding Bureau and is the AWS sustaining member representative of that organization. He served as editor of the recent book, *Design for Welding*, published by the James F. Lincoln Arc Welding Foundation, Cleveland.

### Inspection Tour

**Detroit, Mich.**—The regular monthly meeting of the *Detroit* Section was held on January 11th and involved an inspection tour of the Wolverine Tube Division of the Calumet and Hecla Consolidated Copper Co.

Prior to the plant tour the group was shown a colored movie, "Calumet Mining Operations," portraying the complete story of copper from the mine through the smelter.

K. M. Frink, Plant Manager of Wolverine Tube, had a large staff of supervisory personnel at strategic locations to explain the processing from raw copper to many fabricated tubular parts. The operations were particularly interesting to Detroit Section members, many of whom were similarly concerned with the fabrication of welded and brazed tubing. One hundred and thirty-eight members attended.

The Wolverine Tube Co. was founded in November 1916. In June 1942 it was purchased by the Calumet and Hecla Consolidated Copper Co. The Company's name was changed to Wolverine Tube Div. In January 1947 construction was begun on a new plant in Decatur, Ala., designed to augment the facilities of the Detroit Plant of Wolverine Tube Division. Production began in September 1948 at the Decatur Plant. In July 1950 the General Sales Offices moved to 1850 Guardian Building in downtown Detroit.

Arrangements for the tour were made through the courtesy of H. Y. Bassett, vice-president and general manager, and R. C. McCoy, of the Industrial and Public Relations Depts.

### Rigid Frame Design

**Fort Wayne, Ind.**—Martin P. Korn, AWS, Consulting Engineer for Giffels and Vallet, Inc., Detroit, was the speaker at the January 18th meeting of the *Anthony Wayne* Section held at the Indiana Technical College.

Mr. Korn's talk was in simple language on structural behavior of the rigid frame with fast moving panorama sketches and slides of living structures representing Yesterday, Today and Tomorrow.

He told of his experiences in designing from 1910 to the present time. Also of some of the larger structures in the country with special stress on creative designs possible through employing welded rigid frames. Mr. Korn explained the welded rigid frame of the rapid transit subways in New York, and the making of vast savings in steel tonnage and costs. At the present time he is consultant for Giffels and Vallet on the world's largest convention hall and exhibit building for the new Civic Center in Detroit with all-welded rigid frames spanning distances without precedent.

His subject "Adventures in Rigid Frame Design" was enjoyed by all. The all-welded design slide pictures of the Allen County War Memorial Coliseum were very interesting. This building is now being completed and was designed by Ralph E. Coblentz of A. M. Strauss, Inc.

One hundred and five members, guests, architects and engineers attended the meeting.

### Welding Metallurgy

**Grand Rapids, Mich.**—Dr. A. J. Smith, head of the Department of Metallurgy in the School of Engineering at Michigan State College, gave a lecture on "Welding Metallurgy" at the January 29th meeting of the *Western Michigan* Section held in the Auditorium of the Grand Rapids Public Museum. The attendance was small due to weather conditions but all who came enjoyed the session very much and went home with some excellent tips on all phases of welding, particularly steel.

**WELDING CONNECTORS**

Saxe Welding Connection Units position and secure structural parts to be welded.

Clip K3A permits an adjustable connection.

These widely used units eliminate all hole punching, and, with welding, produce the most economical, safe, and quickly erected structural frame.

*Write for 1951 edition, Structural Welding Practice Manual.*

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an ACCO product for Stainless Steel WELDING

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GAS Welding Rods
made by
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BURNING...
stable even at lower heats

SLAG...
clean, easily removed

COATING...
resists cracking down to very short stubs

SELECTION...
complete line for welding every type of stainless

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Monessen, Pa., Atlanta, Chicago, Denver, Detroit, Los Angeles, New York, Philadelphia, Portland, San Francisco, Bridgeport, Conn.

PAGE Welding Electrodes AND Rods

Dr. Smith received his Ph.D. degree in metallurgy from Yale University in 1937. Until 1948 he held the position of Assistant Director of Research with the Lunkenheimer Co. of Cincinnati, Ohio. He has written a number of papers on welding cast and wrought steels for power plant use. He is a member of the ASM, the AIMME, The Iron and Steel Institute and the ASTM.

Following the meeting coffee and spudnuts were served.

## Fabrication and Design

**Houston, Tex.**—The largest turnout of members and guests that the *Houston* Section has ever had—206—attested to the interest in the talk given by LaMotte Grover, AWS, on "Fabrication and Design for Welded Construction," at the January meeting held on the 24th at the Ben Milam Hotel, this city. Mr. Grover is a director-at-large of the AWS and Welding Engineer for the Air Reduction Sales Co., New York.

In his talk Mr. Grover discussed various structures utilizing welded fabrication and the savings effected through the use of welding. He further discussed materials now in use for structural fabrication, including the use of aluminum, steels and the alloys thereof. His talk was well illustrated with slides which added to the interest. Especially so when Mr. Grover stated the picture of one of the larger buildings in this area is still the largest all-welded structure in the world. Several slides showed buildings in this area and it was pointed out by Mr. Grover that this part of the country was a leader in the field of welded structural buildings and that probably well over 50% of the tonnage of structural steel fabricated into buildings was being done in Houston and its vicinity.

The Houston Section is continuing the practice of inviting student guests from the colleges in this area. This practice was furthered at this meeting by inviting the Deans of the Engineering Schools at Rice Institute, University of Houston, Texas University, and Texas A & M and the Dean of the School of Technology at the University of Houston, as guests. It was announced that the section will sponsor a quarter-hour television program on the 15th of March which will be devoted to showing the public some of the advantages derived from the art and science of welding. It was announced that 26 new members joined during the fall term and AWS lapel pins were awarded to the members present who had secured two or more new members.

A film, "Fishing Holiday in Mexico," was shown through the courtesy of Humble Oil.

## Jigs and Fixtures

**Kansas City, Mo.**—A. N. Kugler, AWS, Air Reduction Sales Co., New York, spoke on "Jigs and Fixtures for Welding" at the Nov. 15, 1951, meeting of the *Kansas City* Section, held at Fred Harvey's Pine Room, Union Station.

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WELDING CLAMPS
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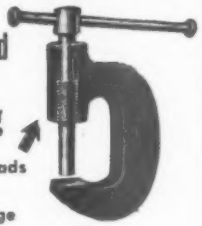

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Mr. Kugler is a Mechanical Engineer in the Technical Sales Dept. of the Air Reduction Sales Co., specializing in the application of welding to various industries. He has had extensive experience in the welding of pipe for oil, gas, steam and water service. Mr. Kugler also has participated in the development of Multilayer Oxyacetylene Welding of Carbon Molybdenum Steel Pipe. He is author of many papers on the subject and has prepared a number of welded machinery designs.

Mr. Kugler graduated from Stevens Institute of Technology in 1925. He is a licensed Professional Engineer in New York and New Jersey, and is a member of several engineering societies.

Mr. Kugler covered new methods, applications and processes in his extemporaneous, semitechnical talk which was illustrated with slides.

## Welding in Education

**Kansas City, Mo.**—Julius Heuschkel, AWS, Manager of the Westinghouse Electric Corp. Research Laboratories' Welding Section, discussed present-day welding as applied to industry and related modern practices to the requirements of the existing engineering educational problems in his talk entitled "Welding in American Engineering Education," which was presented at the Jan. 17, 1952, meeting of the *Kansas City* Section held at Fred Harveys.

Mr. Heuschkel is Chairman of the AWS Resistance Welding Committee and Vice-Chairman of the AWS Educational Committee. He has also been engaged in welding development activities for the U. S. Navy Dept. and the U. S. Steel Corp.

## Silver Alloy Brazing

**Long Beach, Cal.**—An excellent talk on the subject "Design for Silver Alloy Brazing" was given by Roger J. Metzler, AWS, Development Engineer, Handy & Harman, New York, before the January 18th dinner meeting of the *Long Beach* Section held at Miller's Restaurant here.

Mr. Metzler attended Pratt Institute and Columbia University. He has been associated with the welding industry in the field of metallurgy for many years, having served with the Bendix Aviation Corp., the B-M Heat Treating Co. and the Breeze Corp. He is currently associated with Handy and Harman as development engineer on special products. He is co-author of "Engineering Alloys," a directory of proprietary alloys, and the author of several technical papers on metal alloys. He is a member of the AWS New Jersey Section, American Society for Metals, and Army Ordnance Assn.

## Training Welding Operators

**Louisville, Ky.**—Nicholas F. Kiernan, AWS, District Manager, Metal and Thermit Corp., Newark, N. J., delivered an address on "Training of Welding Operators" at the January 22nd meeting of the *Louisville* Section.

A motion picture "Mass Production of Massive Parts" was also shown.

The Louisville Section has found that the buffet lunch followed by the speaking pleases the membership most.

## Plant Tour

**Milwaukee, Wis.**—The Directors of the *Milwaukee* Section were guests of the Falk Corp., Milwaukee, on January 7th. After a fine dinner, the group saw a preview of the slides prepared for the January 21st Symposium on Welding meeting at Marquette University. After the meeting, an extensive tour of the plant was enjoyed by everyone. Thanks were expressed to R. J. Fisher, AWS, and E. Klumpp, AWS, for a grand evening.

The 1952 Educational Course, held Monday evenings, at Marquette University, has come to a close with record attendances. The windup was a successful plant tour on February 4th of the Allis-Chalmers' Tank Shop at West Allis.

## Resistance Welding

**Milwaukee, Wis.**—The regular monthly meeting of the *Milwaukee* Section held on Friday, January 25th, at the Ambassador Hotel, featured an old-timer to the Resistance Welding field—R. T. Gillette, AWS, Consulting Engineer, Precision Welder and Machine Co., Cincinnati, Ohio. Mr. Gillette has long been recognized as one of the world's leading authorities on resistance welding.

He joined the General Electric Co. in 1902 as a member of the research laboratory. During the first World War he was in charge of manufacturing parts for X-ray units for field hospitals abroad, and later worked on tungsten contacts for automobile ignition systems.

He was instrumental in developing electric furnace brazing at G. E. and won the Chas. A. Coffin Foundation award for his work on welding dissimilar metals with the use of Elkonite electrodes.

The meeting was topped off with a General Electric film "This Is Resistance Welding."

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### Election of Officers

**Nashville, Tenn.**—The *Nashville* Section, which has been inactive, although there is sufficient enthusiasm in this area to maintain a very active Section, had a reorganization meeting October 22nd, which was attended by a dozen of the more enthusiastic members. The dinner meeting was held in the Maxwell House and two sound films on the welding of aluminum were shown.

Another meeting was held on January 16th, with fourteen in attendance. Dinner was served at the Maxwell House followed by showing of the film "Making and Shaping of Steel" and election of officers, as follows: *Chairman*, G. E. Daniels; *Vice-Chairman*, H. H. O'Brien; *Secretary*, Fred T. Wilson; and, *Treasurer*, Miller Minton.

### Rockets

**Newark, N. J.**—Willy Ley, Author and Consultant, gave a very interesting talk on the subject of rockets before a joint meeting of the AWS *New Jersey* Section and the Metropolitan Section of the ASME. Several women and children were also in attendance at the meeting. Mr. Ley described the early stages of rocket manufacture in which compressed gas in the tanks forced the fuel and oxidizer into the combustion chamber. He carried the design down to the present which uses a steam turbine driving two pumps for forcing the alcohol and liquid oxygen into the combustion chamber. The decombustion of hydrogen peroxide serves as a source of steam to drive the turbine. The highest flight yet achieved with a Viking type rocket is 135 miles, and a two-stage rocket is now under construction which will allow flights up to 250 miles. Mr. Ley and others have made calculations for a three-stage rocket which could form a 1000-lb. planet at a height of 350 miles, which would continuously circle the earth in 1 hour and 5 minutes.

A sound color motion picture entitled "The Viking" was shown through the courtesy of the Navy Dept.

After the meeting snacks, refreshments and social hour were enjoyed.

### Pipe Welding Codes

**New York, N. Y.**—F. S. G. Williams, Manager of Engineering Standards, Taylor Forge and Pipe Works, New York, was the speaker at the *New York* Section meeting on January 8th at Schwartz Restaurant, 54 Broad St.

Mr. Williams sketched the background of the principal codes governing the design and construction of pressure piping and pressure vessels in land service and commented briefly on the code-writing bodies who have jurisdiction on Maritime installations. The philosophies around which code regulations are established were discussed, with particular reference to welding, which is recognized today as a principal method construction and installation. Mr. Williams pointed out that the reasons or thinking behind code rules are frequently more important to the engineer than the rules themselves.

This meeting was the last of a series devoted to pipe and pressure vessel work.

### Structural Steel Welding

**Oklahoma City, Okla.**—LaMotte Grover, AWS, Welding Engineer for the Air Reduction Sales Co., New York, was the speaker at the January 22nd meeting of the *Oklahoma City* Section held at the Biltmore Hotel and attended by 85 members and guests.

Mr. Grover talked on Structural Steel Welding, discussing welded fabrication and construction procedures, design features and materials for welded construction; also touching on Aircomatic Welding and the oxyacetylene processes as applied to maintenance and reclamation operations in the railroad industry. Following Mr. Grover's talk many questions relative to structural fabrications were discussed and answered. The meeting was concluded with refreshments.

The Section wishes to compliment Mr. Grover on his authoritative knowledge and outstanding expressive ability.

### Plant Tour

**Peoria, Ill.**—A tour of the R. G. LeTourneau, Inc., plant was made on December 19th by thirty members of the *Peoria* Section. Following a thirty-minute question-and-answer period at the end of the tour, the host served coffee and doughnuts.

### Resistance Welding

**Peoria, Ill.**—William H. Klingeman, AWS, Sales Manager, Precision Welder and Machine Co., Cincinnati, Ohio, presented an interesting and instructive address on "Application and Developments in Resistance Welding," which covered resistance welding from the early stages through present developments and uses, at the January 21st meeting of the *Peoria* Section held at the Sazarac Restaurant. Sixty-one members and guests were served an excellent chicken dinner.

A 16-mm. sound, color film "This Is Resistance Welding" was shown through the courtesy of the General Electric Co.

Questions were asked and discussed during the showing of the slides. A short discussion followed the showing of the picture.

### Dinner Dance

**Philadelphia, Pa.**—The Annual Welding Society Party sponsored by the *Philadelphia* Section will be held on May 17, 1952. Dinner and an evening of dancing is planned.

### Design for Brazing

**Phoenix, Ariz.**—The regular monthly meeting of the *Arizona* Section was held at the Hotel Westward Ho, Phoenix, on the evening of January 16th. For this dinner meeting the Section was honored to have Roger J. Metzler, AWS, Develop-

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ment Engineer for Handy and Harman, New York, as principal speaker.

The subject of Mr. Metzler's talk was "Design for Silver Alloy Brazing." He also presented a most interesting colored sound film on the "Fundamentals of Silver Brazing."

In addition to the regular membership, the meeting was attended by approximately thirty-two guests.

## Commercial Testing Laboratories

**Portland, Ore.**—At the January 15th dinner meeting of the *Portland* Section held at the Mallory Hotel, B. N. Woods of the Charlton Laboratories, this city, outlined just what a laboratory consisted of that was in the commercial testing business. He also covered what type of personnel is necessary for such an enterprise as well as the facilities involved. Inspection and qualification of welders were also discussed.

After Mr. Woods' talk the audience was invited to make an inspection tour of the Charlton Laboratories, which they did, and which turned out to be a very interesting field trip. They saw all the equipment the laboratory uses in testing weldments as well as that used for other types of tests.

This was a very instructive and informative evening.

## Question-and-Answer Night

**Richmond, Va.**—An impromptu meeting of the *Richmond* Section involving a question-and-answer period turned out to be one of the most interesting meetings of the season. Two opposing teams competed for prizes. These teams were the Blue Team and the Gray Team. The Blue Team consisted of Capt. W. R. Thomas, G. G. McDearmon, Z. T. Stinson, J. S. Donnelly and Norman Schrader. The Gray Team consisted of Capt. A. J. Mobley, Maynard Hipwell, G. J. Femiani, Fred Mayers and Lee A. Kramer. The Judges were A. C. Worley, Paul Hickman and J. M. Gorrie. All those taking part were members of the AMERICAN WELDING SOCIETY. Each team was provided with eleven questions on welding, gas cutting and related phases. The Gray Team won. Everbody was enthused and a good time was had by all.

## Tooling for Automatic Welding

**Rochester, N. Y.**—Cecil C. Peck, AWS, President of the Cecil C. Peck Co., Cleveland, Ohio, was the guest speaker at the January meeting of the *Rochester* Section. His subject, "Tooling for Automatic Welding," was well received and illustrated with the use of many slides showing special fixtures designed and built for high-speed production welding.

L. Smith, member of the Kiwanis Club, was the coffee speaker. His subject "Operation Alarm Clock," dealt with the importance of every qualified voter's duty to register and vote for the candidate of his choice.

A film, "Manufacture of Stainless Strip," was shown and well received.

## Stainless Steel Alloys

**Saginaw, Mich.**—Gordon Parks, Welding Engineer, Solar Aircraft Co., Des Moines, Iowa, gave an excellent technical talk on the subject, "Arc, Gas and Resistance Welding of High Temperature Stainless Steel Alloys," at the January 10th dinner meeting of the *Saginaw Valley* Section held at Zehnder's Hotel, Frankenmuth, Mich.

## Panel Discussion

**Salt Lake City, Utah.**—The Utah territory has had a complete new industrial growth including such industries as Geneva Steel Co., Chicago Bridge & Iron, Commercial Shearing & Stamping and others, plus the expansion of local plants and the areas they covered. A large percentage of the members requested information on the chemical and physical properties of certain carbon steels. It was therefore decided to conduct a panel discussion in very plain "down to the welder level" language of the fundamental differences of some of the more common carbon steel specifications.

H. C. Brimley, Technical Field Representative, of Columbia-Geneva Steel Division, United States Steel Co., acted as moderator, and gave a short introductory talk on the general history of iron and steel in industry. Then in turn he introduced each of the four "panelcers."

The first speaker was L. F. Dobyns, Contact Representative of Columbia-Geneva Steel Division, United States Steel Co. His subject was "Why This Discussion Was Undertaken, and Specifications to Be Discussed."

Mr. Dobyns fully discussed the various engineering and technical societies under which the specifications have been developed. (ASTM, SAE, etc.). He pointed out the essential differences, origins and developments of the specifications and a general discussion of their uses.

The second speaker was W. C. Dyer, Superintendent of Metallurgical Chemical Inspection, Columbia-Geneva Steel Division, United States Steel Co. Mr. Dyer's subject was "Steel Qualities and What They Mean to You." In this portion of the panel, Mr. Dyer, with drawings and charts traced the steel from open-hearth furnace to finished product. He discussed the acquisition of desired chemical properties, types of ingots, treatment in the molds, cropping, rolling, testing and inspection.

The third panel member was R. J. Prout, Chief Inspector, Columbia-Geneva Steel Division, United States Steel Co. His subject was titled "The Chemistry versus the Physical Properties of Plate Steel." Mr. Prout also used many drawings and charts to illustrate the essential differences in the types of plate by controlling the physical properties through limiting the chemical analyses.

The final speaker on the panel was W. E. Wilkins, Chief Engineer, Salt Lake Plant Chicago Bridge & Iron Co. The subject he undertook was "Considerations in Design." Mr. Wilkins very ably put forth factors to be considered in designing. He pointed out weight savings possible due to greater strength in the higher quality, steels, compared weight strength and costs indicated, and actually designed simple vessels on a blackboard and showed percentagewise savings possible.

A question and answer period followed which it was necessary to halt at last due to the lateness of the hour.

## Preheating for Welding

**San Francisco, Cal.**—The first dinner meeting of the season of the *San Francisco* Section was held on Monday, Sept. 24, 1951, at the Engineer's Club. Technical speaker was A. V. Tesman, AWS, Sales Engineer, Tempil° Corp., New York. His subject was entitled "Preheating for Welding." An excellent film, "Steel Builds the West," was shown through the courtesy of the Bethlehem Pacific Steel Corp.

## Edge Preparation for Welding

**San Francisco, Cal.**—Russell H. Rhoades, AWS, Engineer, Linde Air Products Co., this city, was the main speaker at the October 29th dinner meeting held at the Engineers' Club. In his subject, "Edge Preparation of Plate for Welding," Mr. Rhoades discussed the equipment and methods required to obtain single and multiple bevels on plate edges prior to welding. A color film illustrated both single- and multiple-bevel cutting operations while black and white slides were used to show typical large installations in various parts of the country. Applications applied mainly to mild steel, with a brief coverage of stainless steel and some of the nonferrous alloys.

Also shown was an excellent color and sound film "Building for the Nations" which was shown through the courtesy of the Columbia Steel Co., San Francisco. This is a United States Steel production and covered the highlights of the fabrication and erection of the structural steel work on one of the most important buildings in the world—The Secretariat Building of the United Nations Headquarters in New York City.

Coffee speaker was Edwin M. Wilson of the National Assn. of Manufacturers, who very ably discussed the subject "The Price of Freedom."

## Inert Arc Welding

**San Francisco, Cal.**—Grover Hughes, Shipyard Welding Engineer, and Walter Danton, AWS, Welding Foreman of the San Francisco Naval Shipyard, were the speakers at the November 26th dinner meeting of the *San Francisco* Section held at El Curtola Restaurant, Oakland. Their joint presentation was a discussion of the developments in the inert gas shielded arc process based on the most recent industry and laboratory experience. Design considerations, weld groove preparation and welding procedures as well as typical applications were covered. The opinions expressed by the speakers were based on their own personal experiences and research in the welding field.

An excellent coffee talk entitled "Push Button Warfare" was made by H. G.

Stevens, Director of Community Services, Bay Area Council; also Comdr. U.S.N.R., assigned to Speakers Bureau, Public Information Office, 12th Naval District.

### Christmas Party

**San Francisco, Cal.**—The Annual Christmas Party of the *San Francisco* Section was held on December 7th at the Lake Merced Golf and Country Club with 108 present. The program consisted of "Goodfellowship," followed by a roast beef dinner, the awarding of door prizes and a floor show.

### Resistance Welding

**Schenectady, N. Y.**—J. Heuschkel, AWS, Manager of Welding, Westinghouse Electric Corp., East Pittsburgh, Pa., discussed the need of closer cooperation between the Resistance Welding Machine Manufacturers and the Resistance Welding Control Manufacturers, at the December 6th meeting of the *Northern New York* Section held at Crossroads, Lathams, N. Y. He emphasized the need of education in the welding field, particularly in the trade schools and at college levels. He also spoke about the need of a control system for welding procedures used in manufacturing organizations.

After an active question and answer period, a movie on hunting big game in Alaska was shown.

### Rigid Frame Design

**South Bend, Ind.**—On January 17th, the *Michiana* Section, with architects and civil engineers of the area as their guests, heard Martin P. Korn, AWS, Consulting Engineer with Giffels & Vallet, Architects, Detroit, Mich., discuss the rigid frame design in building construction. In his inimitable manner of speaking, Mr. Korn pointed out the advantages of this type of arch over the conventional girder and beam method of making bridges and large buildings. He also pointed out how welding is a "natural" for making these frames, because the continuity of stress flow that welded joints allow is one of the main factors in the favorable strength/weight ratio which the frames enjoy.

Mr. Korn was a pioneer in this type of construction. Growing up with it as he did, he is equally cognizant of its weaknesses and its advantages. By means of models, sketch and slides he showed what to do and what to guard against in order to make successful application of these frames. The crowning achievement of his sponsorship has been the approval of rigid frame construction for the projected multimillion dollar exhibition hall for Detroit. When built, it will contain the largest column-free room in the world, a tribute to the cooperation of architects and welding engineers.

### Resistances Welding

**Worcester, Mass.**—Ivar W. Johnson, AWS, Electrical Engineer for the General Electric Co., Schenectady, N. Y., presented an interesting and clear-cut lecture on "Resistance Welding" at the January 30th meeting of the *Worcester* Section held at the Tower House. Sixty members and guests were present.

In the course of his talk Mr. Johnson pointed out the advantages of slope control, such as more spots between electrode cleaning, longer electrode life, brazing applications and projection welding of aluminum.

A special period was held before dinner with the showing of a film entitled "Eagles vs. All Stars."

### Plant Visit

**Youngstown, Ohio.**—The *Mahoning Valley* Section started their 1951–52 year on Oct. 25, 1951, with a very interesting plant visitation to the Grove City, Pa., works of the Cooper Bessemer Corp., manufacturers of Diesel engines. Preceding the plant visit, 85 members of the Section enjoyed a buffet supper at the Penn Grove Hotel. R. Kymer, Engineer of the Cooper Bessemer Corp. gave a short descriptive talk on "Weldments vs. Castings in the Diesel Engine Field," and pointed out several things of interest to watch for in the plant.

Reproduced herewith is a picture of the officers and executive committee taken at the above meeting.

L. W. Williams, AWS, Manager of Technical Service, Lukens Steel Co., Coatesville, Pa., was the speaker at the November 15th meeting. Mr. Williams accompanied his talk on the subject "The Manufacture and Fabrication of Clad Metals" with a sound moving picture. Mr. Williams is an outstanding authority on this subject as well as a very interesting speaker. In his talk he pointed out some of the highlights in the manufacture of clad steels, and then went into considerable detail on the welding and other forms of fabrication of the materials.

No meeting was held during the holidays in December.

"The Repair of Heavy Wall Pressure Vessels in the Field" was the topic of the Jan. 17, 1952, meeting. R. J. Berlesky, AWS, Research Engineer with the Babcock and Wilcox Co. of Barberton, Ohio, was the speaker. His talk covered actual experiences and practices used by him for repair welding of heavy walled pressure vessels. Some of his experiences in repairing cast steel vessels with welding are unique and make a very good talk. Mr. Berlesky's talk was illustrated with slides.

Dr. R. D. Stout, AWS, of Lehigh University, will be the speaker at the March 20th meeting. His subject will be "Elementary Metallurgy for Welding." The student body and faculty of the Metallurgical Dept. at Youngstown College will be guests of the Section for a dinner and meeting that night. The membership of the Mahoning Valley Section realize the critical shortage of Welding Engineers in the United States, and by inviting these students to this meeting they are hoping to interest a few college men in the profession.

The last two meetings of the year will be Plant Visits. In April the Section will visit the Federal Machine and Welder Co. of Warren, Ohio. The Mullins Mfg. Co. of Warren, Ohio, will be visited in May.

To stimulate further interest in our Section and to make the Section more useful to the industries in the area, a plan has been formed whereby any member of the AMERICAN WELDING SOCIETY in the Section may ask any technical question in the metals joining field, either in writing or orally. These questions will be turned over to the Technical Chairman, Dr. I. A. Oehler, who has the privilege of asking any other member in the Section who has had experience in the field about which the question is asked to help answer the question. The answer may either be in writing or given orally at the next Section meeting. Most Sections do this unofficially but with a definite plan or program set up, the Mahoning Valley Section hopes to create an activity which will help promote the AWS in this section.

*Standing (left to right): R. Kymer, speaker; L. P. Dunlap, I. A. Oehler, N. G. O'Halie, W. F. Buchanan, R. E. Heltzel, Vice-Chairman. J. H. Cordner, Secretary-Treasurer; O. H. Kuhlke, Chairman. Seated (left to right): H. L. Lyon, J. R. Barefoot, H. L. Glass, J. Maternach, Jr., W. D. Colbert, W. L. Thompson, G. C. Fogg*

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*Supplement to the Welding Journal, March, 1952*


# Projection Welding of Steel in Heavy Gages and in Dissimilar Thicknesses

*Effects of weld current, weld time electrode force and projection dimensions on weld formation and weld quality in projection welding*


*by Ernest F. Nippes and John M. Gerken*



## SUMMARY

IN THIS investigation the effects of weld current, weld time, electrode force and projection dimensions on weld formation and weld quality were studied.

When welding both the 0.187 in. to 0.187-in. steel and the 0.250 in. to 0.250-in. steel, it was necessary to increase the electrode force at the termination of the weld current to minimize porosity. In addition, it was necessary either to apply an increased electrode force at the beginning of the weld, or to start the weld current at a low value to prevent flashing of the projection when the weld initiated. The projection dimensions were not critical in their effect on weld quality.

When welding 0.040-in. steel to thicker gages, the same projection dimensions and electrode force used to weld 0.040 in. to 0.040-in. steel could be employed. However, the welding current and weld time had to be increased as the thickness of the thicker sheet was increased. A more uniform weld strength over the recommended current range resulted when the projection was placed in the thicker sheet rather than in the thinner sheet.



**Ernest F. Nippes** and **John M. Gerken** are connected with the Welding Laboratory of the Rensselaer Polytechnic Institute, Troy, N. Y.


## INTRODUCTION

The research on projection welding, as covered in this report, includes the welding of A.I.S.I.-1010 steel in similar thickness of 0.187 in. and 0.250 in. and dissimilar thickness combinations of 0.040 in. to 0.062 in., 0.125 in., 0.187 in., and 0.250 in. The investigation of projection welding, which has been in progress for some time at the Rensselaer Polytechnic Institute,[1-3] was terminated on June 30, 1951. This program was guided by the Resistance Welding Committee and was financially supported by the Welding Research Council for the purpose of broadening the knowledge of projection welding and establishing optimum welding conditions for various gages and types of steel.

## EQUIPMENT

Welding of the 0.187 in. to 0.187-in., and 0.250 in. to 0.250-in. material was done on a 175-kva. toggle press-type welder with a dual air pressure system. An additional electrode forge force could be applied or removed at any point during the weld period. Either $1^1/_4$- or $2^1/_4$-in. diameter electrodes were used on this machine. Electrode force was calibrated using a simple steel beam supported at both ends with a load applied at two points about one-third of the way in from the ends. Readings were obtained from two SR-4 type electric strain gages cemented to the top and bottom surfaces of the beam. The gage itself

**Table 1—Chemical Analysis**

| Item No. | A.I.S.I. No. | Thickness, in. | % C | Mn | P | S | Si | Cu | Ni | Cr |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1010 | 0.010 | 0.11 | 0.35 | 0.029 | 0.024 | Trace | ... | ... | ... |
| 2 | 1010 | 0.020 | 0.08 | 0.36 | 0.021 | 0.019 | Trace | ... | ... | ... |
| 3 | 1010 | 0.040 | 0.08 | 0.36 | 0.007 | 0.028 | 0.012 | 0.04 | 0.06 | 0.05 |
| 4 | 1010 | 0.062 | 0.08 | 0.36 | 0.007 | 0.028 | 0.012 | 0.04 | 0.06 | 0.05 |
| 5 | 1010 | 0.125 | 0.08 | 0.39 | 0.010 | 0.027 | 0.010 | 0.06 | 0.05 | 0.04 |
| 6 | 1010 | 0.187 | 0.09 | 0.35 | 0.008 | 0.028 | ... | ... | ... | ... |
| 7 | 1010 | 0.250 | 0.09 | 0.35 | 0.008 | 0.028 | ... | ... | ... | ... |

was calibrated against a hydraulic testing machine of known accuracy.

Welding of the 0.040-in. sheet to the other thicknesses was done on a 200-kva. air operated spot welder. On this machine an additional forge force could be applied at any point during the welding period but could not be removed until the main welding force was removed. The machine was equipped with a spring-loaded electrode of 500 lb. capacity which was used for most of this work. An electronic weld timer and current control in conjunction with a current regulator and program timer were used for controlling the weld current magnitude and time. Short time weld currents (under 30 cycles) were measured on an I squared T meter which measures the product of the weld current squared and the weld time.[4] Longer time weld currents were measured on a recording type ammeter. Weld times were spot checked on a direct-inking oscillograph.

## MATERIAL AND PREPARATION

The material used in this investigation was A.I.S.I.-1010 steel in the 0.040, 0.062, 0.125, 0.187 and 0.250 in. thicknesses. Chemical analysis of these steels are given in Table 1 and mechanical properties are given in Table 2. This steel was received from the mill in the pickled and oiled condition; however, while in storage the steel became lightly rusted or tarnished. To produce as nearly uniform sheet surface resistance as possible, all weld specimens were first degreased, then pickled in a 50% solution of hydrochloric acid just long enough to remove the light rust. Immediately after pickling, the samples were washed with water, then acetone and dried with a clean air blast.

## TESTING PROCEDURE

Welds which were used to determine porosity and nugget diameter were made in square specimens of the steel. These welds were radiographed to reveal any nugget porosity, then were sectioned, polished and etched with a 10% aqueous solution of ammonium persulphate to permit measurement of the fused zone. The dimensions of the squares were as follows: for welding 0.187 in. to 0.187 in., 2 in.; for welding 0.250 to 0.250 in., 3 in.; for welding 0.040 in. to other thicknesses, 1 in.

Shear strength and normal strength specimens, as

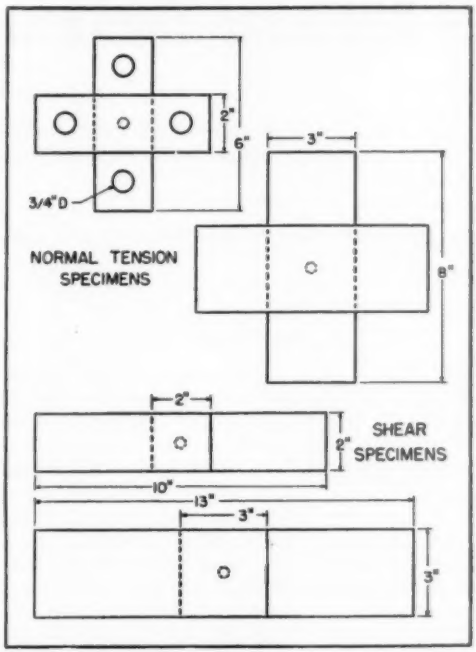


*Figure 1*

**Table 2—Mechanical Properties**

| Item No. | A.I.S.I. No. | Thickness, in. | Yield strength, psi. | Ultimate strength, psi. | Hardness Rockwell "B" | Elongation % in 2 in. |
|---|---|---|---|---|---|---|
| 1 | 1010 | 0.010 | ... | 45,180 | 55* | 31 |
| 2 | 1010 | 0.020 | ... | 43,900 | 63* | 31 |
| 3 | 1010 | 0.040 | ... | 45,350 | 50 | 32 |
| 4 | 1010 | 0.062 | 39,100 | 49,500 | 52 | 32 |
| 5 | 1010 | 0.125 | 40,700 | 43,600 | 52 | 30 |
| 6 | 1010 | 0.187 | 39,200 | 50,100 | 49 | 46.5 |
| 7 | 1010 | 0.250 | 37,400 | 49,500 | 48 | 46.8 |

* Converted from V.P.N. using conversion chart from 1939 A.S.M. *Handbook*, p. 127.

shown in Fig. 1, were used to determine the mechanical properties of the welds. The 2- x 6-in. specimens were used for sheet thicknesses up to and including 0.187 in. and the 3- x 8-in. specimens were used for sheet thicknesses of 0.250 in. and greater. Generally, three values of strength were averaged for each point reported on the graphs to follow.

## PUNCHES AND DIES

Punches and dies used in this research were machined from an air-hardening steel and were hardened and tempered to a hardness of about 53 Rockwell "C." An earlier report[1] indicated that for forming a projection in sheet the volume of the punch should be equal to the volume of its mating die. However, when projections are formed in thicker sheets, metal is also displaced radially outward in the plane of the sheet. This makes it necessary to use a punch having a volume somewhat larger than the volume of the die to obtain a fully formed projection. The amount of extra punch volume, required increases with the ratio of sheet thickness to projection size.

## ELECTRODE TIP MATERIAL

Electrode tip material of the copper-tungsten type, R.W.M.A. Group B, class 11 or 12, with conductivity of 28–30% I.A.C.S. was used for both electrodes when welding the 0.40-in. steel to various thicker gages up to 0.125 in. When welding 0.040 in. to the 0.187- and 0.250-in. steel it became necessary to use a higher conductivity electrode tip material, R.W.M.A. Group A, Class 2, against the 0.040-in. sheet to prevent excessive heating of this sheet.

For welding 0.187 in. to 0.187 in. and 0.250 in. to 0.250 in. the high conductivity tip material, R.W.M.A., Group A, Class 2, was used.

## WELDING 0.187 IN. TO 0.187-IN. STEEL

The projection dimensions used for welding the 0.187 in. to 0.187-in. steel were determined by extrapolating the curves of recommended projection diameter and height versus sheet thickness[1, 2] to 0.187-in. thickness as shown in Fig. 2. Two sets of punches and dies were made to form projections somewhat smaller and somewhat larger than indicated by the extrapolation. The dimensions of the projections were as follows:

| *Projection No.* | *Diameter, in.* | *Height, in.* |
|---|---|---|
| 1 | 0.394 | 0.080 |
| 2 | 0.440 | 0.085 |

Welds were made in 2-in. square specimens at a weld time of 120 cycles (60 cps.) using the No. 1 projection, with electrode forces of 2000, 3000, 4000 and 5000 lb., and currents ranging from 14,000 to 26,000 amp. These welds were radiographed to determine the amount of porosity and sectioned to reveal the fused nugget shape and size. Figure 3 shows the nugget diameter versus welding current for each electrode force.

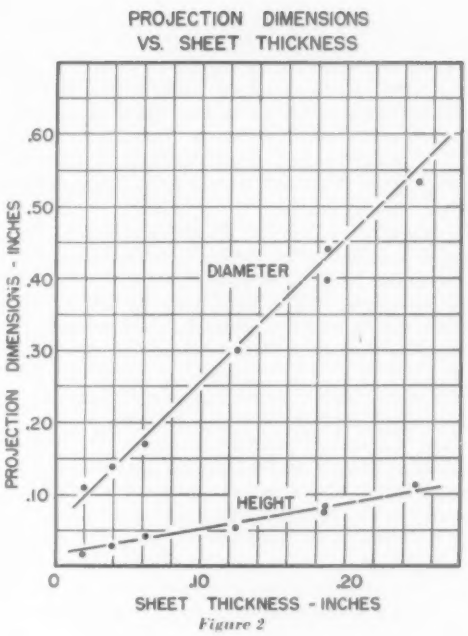

*Figure 2*

A weld fused nugget diameter of somewhat greater than three times the sheet thickness was sought. However, weld nugget porosity resulted with all electrode forces investigated when sufficient weld current was used to produce a 0.60-in. diameter nugget. As would be expected, the amount of porosity was greater at the lower electrode forces. In addition, flashing between the sheets at the start of the weld was also pronounced at the lower electrode forces. This was caused by sluggishness of the movable electrode in

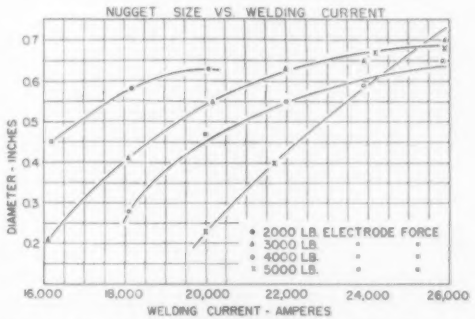

*Fig. 3 0.187 in. to 0.187-in. steel; projection diameter, 0.394 in.; projection height, 0.080 in.; weld time, 120 cycles*

following the initial projection collapse, resulting in a short period of low electrode force.

It seemed unfeasible to use higher electrode forces than 5000 lb. to eliminate porosity and flashing; therefore, it was decided to investigate special electrode force and current sequences. To reduce porosity, a dual pressure weld sequence was used in which the electrode force was increased sharply at the termination of the welding current. Two methods were employed to reduce initial flashing. In one, an electrode force higher than the normal welding force and equal to the terminating force was applied before the start of the welding current and maintained for the first 20 cycles of the welding current. This effectively overcame the sluggishness of the electrode motion when the projection collapsed. This current and electrode force sequence is shown diagrammatically in Fig. 4 (*a*). The second method for reducing flashing was to increase the welding current through two steps of 20 cycles each before the final welding current magnitude was reached. These two current steps were approximately 50 and 75% of the final welding current. This method effectively slowed down the projection collapse so that the movable electrode could follow it and maintain sufficient force to prevent flashing. Figure 4 (*b*) illustrates this current and electrode force sequence. If current slope control[8] is available, it may be used instead of the two steps of low current, increasing from about 40% of weld current to 100% in 30 to 40 cycles weld time.

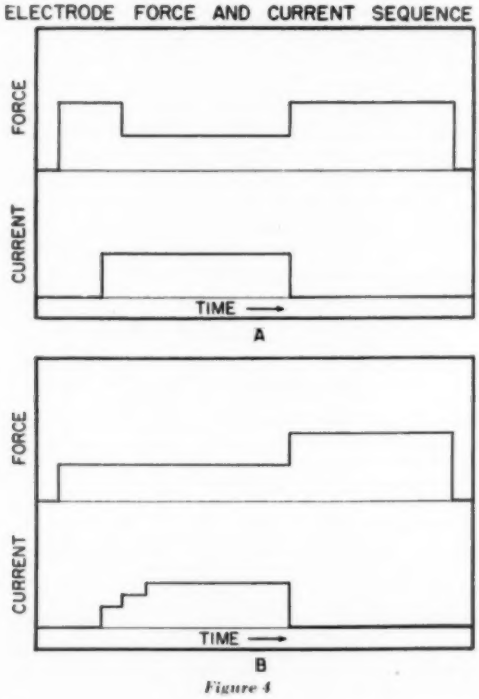


*Figure 4*

Welds were made using these sequences with 2000, 2500 and 3000 lb. welding electrode force and 4000, 5000, 6000 and 7000 lb. total forging electrode force. Both the No. 1 and No. 2 projections were used with the high force start as shown in Fig. 4 (*a*) while only the No. 1 projection was used with the low-current start as shown in Fig. 4 (*b*). The welding time after either the initial high forge force period or the low-current period was 100 cycles in all cases. It was found that with the current necessary to produce a 0.60-in. diameter nugget a forge force of 5000 lb. was ample to eliminate porosity. However, initial flashing was evidenced when using the initial low-current start period in combination with 2000 lb. electrode force. For corresponding conditions the smaller projection, No. 1, was found to produce slightly larger weld nugget diameters than the No. 2 projection; therefore, the No. 1 projection was used for the remainder of the work on this thickness.

To determine the effect of weld time on nugget size welds were made at 3000 lb. welding and 5000 lb. forging electrode force with a high electrode force at the start of the weld, and weld times of 90, 120 and 150 cycles. The results, as shown in Fig. 5, indicated that increasing the weld time from 120 to 150 cycles produced a relatively small increase in nugget diameter. From this a weld time of 120 to 130 cycles was considered as optimum.

Five series of welds were made for the determination of the normal tension and shear strengths of welds under the following conditions:

| *Series* | *Electrode force, lb.* *Weld* | *Forge* | *Total weld time, cycles* |
|---|---|---|---|
| A | 2000 | 5000 | 80 |
| B | 2000 | 5000 | 100 |
| C | 3000 | 5000 | 100 |
| D | 3000 | 5000 | 130 |
| E | 3000 | 5000 | 140 |

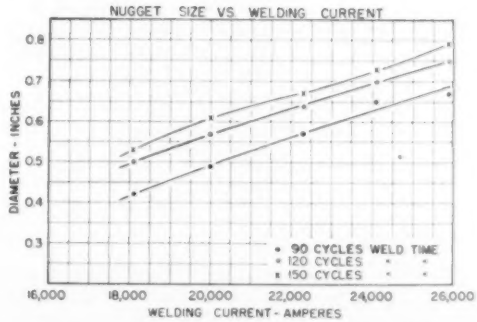


***Fig. 5 0.187 in. to 0.187-in. steel; projection diameter, 0.394 in.; projection height, 0.080 in.; electrode force, 3000 lb.***

For Series A through D, the weld was initiated with the forge force applied and held for 20 cycles of the welding current, then reapplied at the end of the weld time. For Series E the current was increased in two steps of 20 cycles each, as shown in Fig. 4 (*b*), before the final welding current was applied, and the forge force was applied only at the end of the weld. The strengths of Series A and B are shown in Fig. 6 and that of Series C, D, and E are shown in Fig. 7.

The Series A and B welds, with 2000 lb. weld electrode force, expelled profusely at 26,000 amp. which accounted for the drop in shear strength at this current, as shown in Fig. 6. These welds exhibited a "plug" type failure when tested in normal tension at all current values except 10,000 amp. However, the welds tested in shear failed with a "shear" type failure at all currents except 24,000 amp. in which case plug type failures occurred. At 22,000 and 26,000 amp. the failures were sometimes of shear and sometimes of plug type.

Series C welds, identical to Series B welds except that the weld electrode force was 3000 lb. instead of 2000 lb., exhibited no expulsion at 26,000 amp. The normal strength specimens all broke with a plug type failure while the shear specimens broke with a shear type failure except at 26,000 amp. As might be expected, increased welding electrode force displaced the strength-current curves to the right.

Series D and E welds, made with 3000 lb. welding electrode force, were identical except for the method of starting the weld and reducing projection flashing. The effective weld time in both cases was 130 cycles, rather than the 100 cycles used in Series C. The most significant effect of the increase in weld time from 100 to 130 cycles was the increase in normal tension strength, the shear strength being not greatly improved, as shown in Fig. 7. For Series D and E welds all normal tension specimens broke with a plug type failure. The shear specimens of Series D broke with a shear type failure up to a welding current of 24,000 amp. at which point the transition to a plug failure took place.

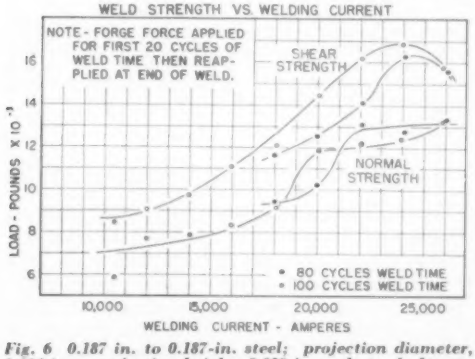


*Fig. 6 0.187 in. to 0.187-in. steel; projection diameter, 0.394 in.; projection height, 0.080 in.; electrode force—weld 2000 lb., forge 5000 lb.*

The transition from shear to plug type failure for Series E welds took place over a current range from 22,000 to 24,000 amp.

It is apparent from Fig. 7 that both Series D and Series E welds had approximately equal strengths for a given current value between 23,000 and 26,000 amp. but that below 23,000 amp. the E series welds were somewhat stronger. The recommended conditions for welding 0.187 in. to 0.187-in. steel are given in Table 3 and are summarized in Table 9 for comparison with other thicknesses.

**Table 3—Recommended Conditions for Welding 0.187 In. to 0.187-In. Steel**

| | |
|---|---|
| Electrode force, lb | 3000 |
| Forge force, lb | 5000 |
| Weld time, cycles | 130* |
| | 140† |
| Weld current range, amp | 23,000–25,000 |
| Projection diameter, in. | 0.394 |
| Projection height, in. | 0.080 |

* With forge force applied for first 20 cycles of weld time.
† With 2-step current starting in 20-cycle steps of 50 and 75% of welding current. If slope control is available it may be used in place of the 2-step current, starting at about 40% of welding current and sloping up in 30 to 40 cycles.

## WELDING 0.250 IN. TO 0.250-IN. STEEL

The dimensions of the projection used for the 0.250 in. thickness were determined by extrapolating the projection dimensions versus sheet thickness for other thicknesses. The dimensions determined, as shown in Fig. 2, were 0.532 in. diameter, 0.110 in. height. In order to save time and because small variations in projection dimensions are not critical, only this size projection was used for welding the 0.250 in. thickness.

Welds were made in 3-in. square specimens using this projection with 3000, 4000 and 5000 lb. electrode force, a weld time of 150 cycles, and weld currents from 22,000 to 30,000 amp. In view of the necessity of employing a forge electrode force at the end of the weld and either a forge force or low current at the start of the weld when welding 0.187 in. to 0.187-in. steel, this same procedure was immediately applied to the welding of the

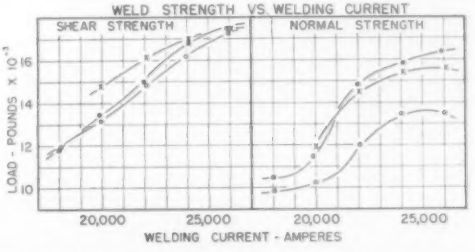


*Fig. 7 0.187 in. to 0.187-in. steel; projection diameter, 0.394 in.; projection height, 0.080 in.; electrode force—weld 3000 lb., forge 5000 lb.*

○ 100 cycle weld time—forge force for first 20 cycles and end of weld
● 130 cycle weld time—forge force for first 20 cycles and end of weld
× 140 cycle weld time—2-step current for first 40 cycles

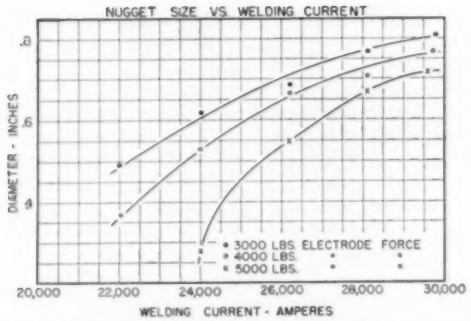


*Fig. 8 0.250 in. to 0.250-in. steel; projection diameter, 0.532 in.; projection height, 0.110 in.; weld time, 150 cycles; forge force 8000 lb. applied for first 25 cycles and end of weld*

0.250-in. steel. A forge force of 8000 lb. was applied for the first 25 cycles of weld time and reapplied when the weld current was terminated. The welds were radiographed, sectioned, etched and the fused nuggets measured. The results, Fig. 8, indicated that increasing the electrode force from 3000 to 4000 lb. did not greatly reduce the nugget size but a further increase to 5000 lb. substantially reduced the nugget size with welding currents below 27,000 amp. With all three electrode forces used, there was no evidence of expulsion up to 30,000 amp. electrode force; however, a small amount of porosity appeared at this current.

Welds were made with 4000 lb. electrode force, 150 cycles weld time, 28,000 amp. welding current and forge forces of 4000, 6000, 8000 and 10,000 lb. When using 4000- and 6000-lb. forge forces, porosity was found to be extensive, but was absent at 8000 and 10,000 lb.

To determine the effect of weld time on nugget diameter and porosity, welds were made at 150, 200, 250 and 300 cycles weld time. A weld force of 4000 lb. and a forge force of 8000 lb. were used for these experiments.

The results, presented in Fig. 9, show that there was practically no increase in nugget diameter with an increase in weld time from 250 to 300 cycles. It will also

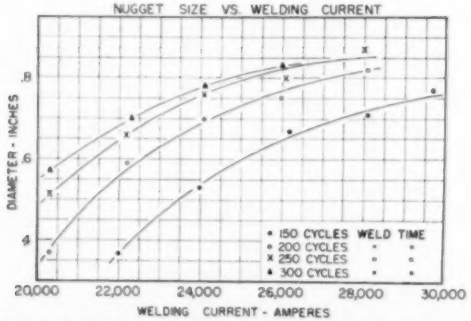


*Fig. 9 0.250 in. to 0.250-in. steel; projection diameter, 0.532 in.; projection height, 0.110 in.; weld force 4000 lb., forge force 8000 lb. applied for first 25 cycles and end of weld*

be noticed that the diameter-current curves tended to flatten off above 26,000 amp. weld current for 250 and 300 cycles weld time. At 200, 250 and 300 cycles weld time a small amount of porosity appeared at 24,000 amp. weld current and this porosity increased somewhat as the current was raised to 28,000 amp. From these considerations, a weld time of 225 cycles was considered to be optimum.

Strength-current curves were determined under the following conditions:

| Series | Electrode force, lb. Weld | Forge | Total weld time, cycles |
|---|---|---|---|
| F | 4000 | 8000 | 225 |
| G | 4000 | 8000 | 250 |

The Series F welds were made with a forge force applied at the beginning of the weld and maintained for the first 25 cycles of weld current The Series G welds were started with reduced current in two steps of approximately 40 and 70% of the final welding current.

The shear strength- and normal strength-current curves for Series F and G welds are shown in Fig. 10. It will be noted from these curves that the method of starting the weld had essentially no effect on the normal or shear strengths of the welds. All normal tension weld specimens broke with a plug type failure, except the Series F welds at 14,000 amp. weld current. The transition from shear to plug type failure for the shear specimens took place at 30,000 amp. for the Series F welds and over a range of 28,000 to 30,000 amp. for the Series G welds. No expulsion was noticed over the range of current used for these tests.

The conditions recommended for welding 0.250 in. to 0.250-in. steel are as given in Table 4 and also in Table 9.

**Table 4—Recommended Conditions for Welding 0.250 In. to 0.250-In. Steel**

| | |
|---|---|
| Electrode force, lb. | 4000 |
| Forge force, lb. | 8000 |
| Weld time, cycles | 225* |
| | 250† |
| Weld current range, amp. | 27,000-29,000 |
| Projection diameter, in. | 0.532 |
| Projection height, in. | 0.110 |

* With forge force applied for first 20 cycles of weld time.
† With 2-step current starting in 25-cycle steps of 40 and 70% of welding current. If slope control is available it may be used in place of the 2-step current, starting at about 40% of welding current and sloping up in 40 to 50 cycles.

## WELDING 0.040-IN. STEEL TO 0.062-IN. STEEL

The conditions for welding 0.040-in. steel to various thicker sheets were determined primarily by measuring the fused nugget diameter and penetration into each sheet of welds made between 1-in. squares of each thickness. This method, which is economical of material, was adopted because the remaining supply of steel in these thicknesses had been almost depleted and it was desired to complete the tests with the same heats

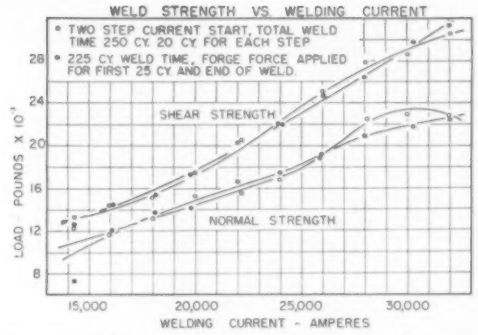


*Fig. 10 0.250 in. to 0.250-in. steel; projection diameter, 0.532 in.; projection height, 0.110 in.; electrode force—weld 4000 lb., forge 8000 lb.*

of steel as originally used for the previous programs.[1, 2] Once weld time and electrode force were determined using this method, the best welding current range was determined from shear strength and normal strength versus current curves.

The conditions previously determined in this laboratory[2] for welding 0.040 in. to 0.040-in. steel are given in Table 9. Based on these conditions welds were made using a projection in the 0.040-in. sheet closely approximating the recommended projection for 0.040 in. to 0.040-in sheet, 450 lb. electrode force and weld times of 15, 20 and 25 cycles. The fused nugget diameter versus weld current over a current range of 6000 to 8500 amp. is shown in Fig. 11. It will be noted that increasing the weld time from 15 to 20 cycles produces a relatively large increase in weld diameter, while a further increase to 25 cycles produces only a small increase in weld diameter. From these results a

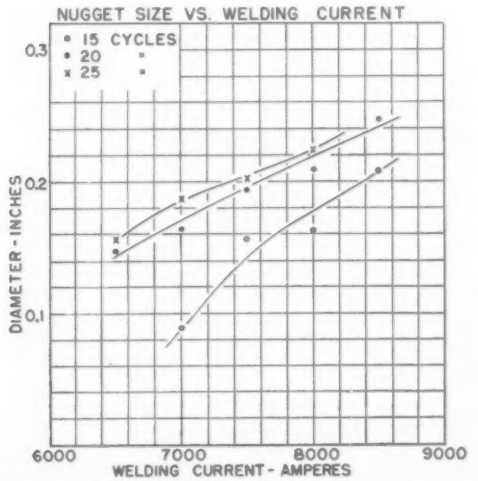


*Fig. 11 0.040 in. to 0.062-in. steel; projection in 0.040-in. sheet; projection diameter, 0.148 in.; projection height, 0.032 in.; electrode force 450 lb.*

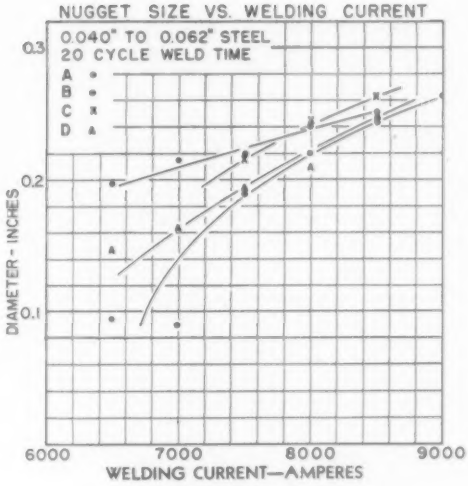


*Figure 12*

***Projection in 0.062-in. sheet***

(*A*) Diameter, 0.148 in.; height, 0.030 in.; electrode force, 600 lb.
(*B*) Diameter, 0.144 in.; height, 0.015 in.; electrode force, 450 lb.
(*C*) Diameter, 0.148 in.; height, 0.030 in.; electrode force, 450 lb.

***Projection in 0.040-in. sheet***

(*D*) Diameter, 0.148 in.; height, 0.032 in.; electrode force, 450 lb.

weld time of 20 cycles was established. Above 7500 amp. the fused zone penetration into each sheet was greater than 50% for all weld times used.

Three series of tests were made with the projection in the 0.062-in. sheet using 20 cycles weld time. The projections and electrode forces used were as follows:

| *Projection diameter, in.* | *Projection height, in.* | *Electrode force, lb.* |
|---|---|---|
| 0.148 | 0.030 | 600 |
| 0.144 | 0.015 | 450 |
| 0.148 | 0.030 | 450 |

Figure 12 shows the nugget size resulting from these tests as a function of welding current. The curve from Fig. 11 with the 0.148 in. diameter, 0.032 in. height projection in the 0.040-in. sheet at 20 cycles weld time is repeated for comparison. It may be seen from Fig. 12 that at 450 lb. electrode force, changing the height of the projection from 0.015 to 0.030 in. had very little effect on nugget size. Increasing the electrode force to 600 lb. moved the curve to the right, thereby increasing the current requirements to produce a given sized weld. It will also be noticed that the placement of the projection in the thin sheet reduced the nugget diameter for a given set of conditions.

Using the following conditions, three series of welds were made for strength-current tests.

| *Sheet with projection, in.* | *Projection, in.* | | *Electrode force, lb.* |
|---|---|---|---|
| | *Diameter* | *Height* | |
| 0.062 | 0.148 | 0.030 | 600 |
| 0.062 | 0.148 | 0.030 | 450 |
| 0.040 | 0.148 | 0.032 | 450 |

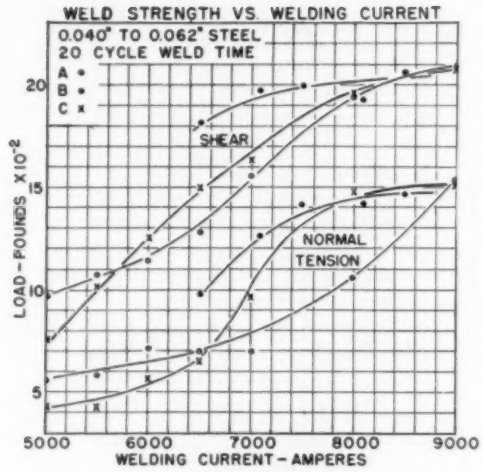


*Figure 13*

***Projection in 0.062-in. sheet***

*(A)* Diameter, 0.148 in.; height, 0.030 in.; electrode force, 600 lb.
*(B)* Diameter, 0.148 in.; height, 0.030 in.; electrode force, 450 lb.

***Projection in 0.040-in. sheet***

(C) Diameter, 0.148 in.; height, 0.032 in.; electrode force, 450 lb.

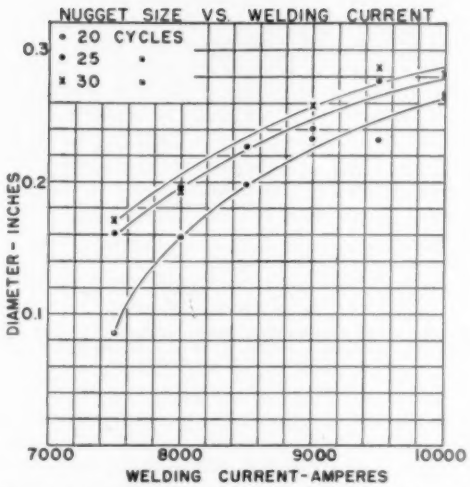


*Fig. 14 0.040 in. to 0.125-in. steel; projection in 0.040-in. sheet; projection diameter, 0.148 in.; projection height, 0.032 in.; electrode force, 450 lb.*

The results of these tests, as shown in Fig. 13, indicate that higher shear and normal tension strengths were obtained over a broader current range by placing the projection in the 0.062-in. sheet and using an electrode force of 450 lb. If the projection is placed in the 0.040-in. sheet, other conditions being unchanged, the maximum shear and normal tensile strengths will be the same as when the projection is in the thicker sheet. However, the permissible current range will be narrower and of a slightly higher value when the projection is in the thinner sheet. When using 600 lb. electrode force the normal tension strength was considerably lower than when using 450 lb.

The conditions recommended for welding 0.040-in. steel to 0.062-in. steel are given in Table 5 and summarized in Table 10.

## WELDING 0.040-IN. STEEL TO 0.125-IN. STEEL

Welds were made joining 0.040-in. sheet to 0.125-in. sheet using the 0.148 in. diameter, 0.032 in. height projection in the 0.040-in. sheet with weld times of 20, 25 and 30 cycles and a current range of 7500 to 10,000 amp. After these welds were radiographed, the nugget diameter versus welding current curves were determined by sectioning. As shown in Fig. 14, increasing the weld time beyond 25 cycles did not effect a large increase in nugget diameter.

At 25 and 30 cycles weld time the nugget penetration was about 0.025 in. into the 0.040-in. sheet and about 0.100 in. into the 0.125-in. sheet, which placed the center of the nugget about 0.040 in. into the thicker sheet. Over the current range of 8000 to 9000 amp. most of the welds contained a small amount of porosity which became excessive at 10,000 amp. Fortunately, the porosity occurred at the center of the nugget, not in line with the interface between the sheets, thereby minimizing the weakening effect of the porosity.

An effort was made to reduce the weld porosity, first, by using a higher and stiffer projection (0.139 in. diameter, 0.045 in. height) at 500 lb. electrode force, and second, by using the same projection (0.148 in. diameter, 0.032 in. height) at 600 lb. electrode force. Since 20 cycles weld time had been found to be inadequate, the weld times used were 25, 30 and 40 cycles. The nugget diameter versus welding current curves for this series of welds are shown in Figs. 15 and 16, respectively. A comparison of Fig. 15 with Fig. 14 shows that at 25 and 30 cycles weld time there is not a significant difference in the fused zone diameter when using the 0.139 in. diameter, 0.045 in. height projection at 500 lb. or the 0.148 in. diameter, 0.032 in. height projection at 450 lb. Furthermore, there was no noticeable reduction of weld porosity when using the higher projection.

**Table 5—Recommended Conditions for Welding 0.040 In. to 0.062 In. Steel**

| *Sheet with projection, in.* | *Projection, in.* | | *Electrode force, lb.* | *Time, cycles* | *Current range, amp.* |
|---|---|---|---|---|---|
| | *Diameter* | *Height* | | | |
| 0.040 | 0.148 | 0.032 | 450 | 20 | 7800–8200 |
| 0.062* | 0.148 | 0.030 | 450 | 20 | 7600–8000 |

* It is suggested that the projection be placed in the 0.062 in. sheet if design and other factors permit.

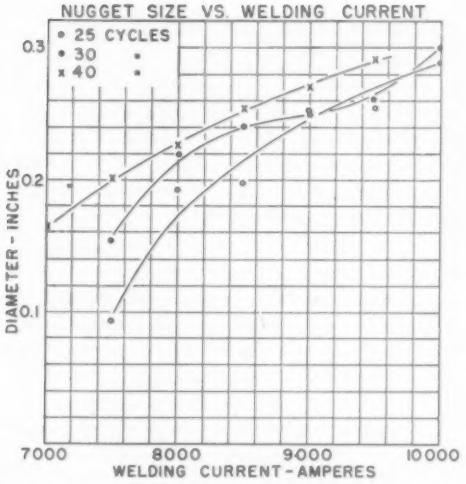


*Fig. 15 0.040 in. to 0.125-in. steel; projection in 0.040-in. sheet; projection diameter, 0.139 in.; projection height, 0.045 in.; electrode force, 500 lb.*

When using the 0.032 in. height projection at 600 lb. electrode force, the nugget diameters were considerably smaller at 25 cycles and somewhat smaller at 30 cycles than those made under similar conditions but with 450 lb. electrode force. This may be illustrated by comparing Figs. 14 and 16. The 600 lb. electrode force was found to reduce the weld porosity only to a small degree when a comparison was made on the basis of equal nugget diameters at each electrode force. Furthermore, when using the 600 lb. electrode force, the nugget penetration into the 0.040-in. sheet was less than 0.020 in. for currents of 8500 amp. or less. In

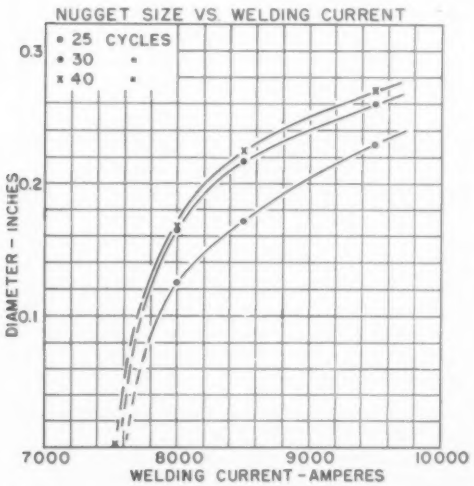


*Fig. 16 0.040 in. to 0.125-in. steel; projection in 0.040-in. sheet; projection diameter, 0.148 in.; projection height, 0.032 in.; electrode force, 600 lb.*

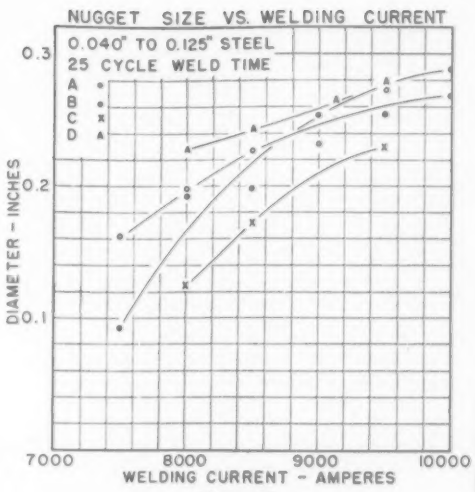


*Figure 17*

***Projection in 0.040-in. sheet***

(*A*) Diameter, 0.148 in.; height, 0.032 in.; electrode force, 450 lb.
(*B*) Diameter, 0.139 in.; height, 0.045 in.; electrode force, 500 lb.
(*C*) Diameter, 0.148 in.; height, 0.032 in.; electrode force, 600 lb.

***Projection in 0.125-in. sheet***

(*D*) Diameter, 0.148 in.; height, 0.026 in.; electrode force, 450 lb.

view of these findings it was decided to use an electrode force of 450 lb., a weld time of 25 cycles, and to neglect the small amount of porosity in the 8000 to 9000 amp. current range.

Welds were made with a 0.148 in. diameter, 0.026 in. height projection in the 0.125-in. steel, using a weld time of 25 cycles, an electrode force of 450 lb. and a current range of 8000 to 9500 amp. The diameter of these welds are plotted in Fig. 17 along with the 25 cycle curves of Figs. 14, 15 and 16 for comparison. Weld porosity was not improved by placing the projection in the thicker sheet; however, placing the projection in the 0.125-in. sheet did have the advantage of producing a flatter nugget diameter-current curve which is above the other curves in the lower current ranges.

Two series of normal tension and shear strength tests were made at 450 lb. electrode force and 25 cycles weld time, one with the projection in the 0.040-in. sheet, and the other with the projection in the 0.125-in. sheet. Figure 18 shows that from 8600 to 9200 amp., neither the normal tension nor the shear strengths were appreciably altered by changing the placement of the projection from the thinner to the thicker sheet. However, below this current range the shear strength decreased more rapidly with the projection in the 0.040-in. sheet, and the normal strength dropped off sharply just below 8000 amp. With the projection in the 0.125-in. sheet, both strength-current curves were flatter, giving a greater current range over which good welds can be made.

The conditions recommended for welding 0.040-in. steel to 0.125-in. steel are given in Table 6 and also in Table 10.

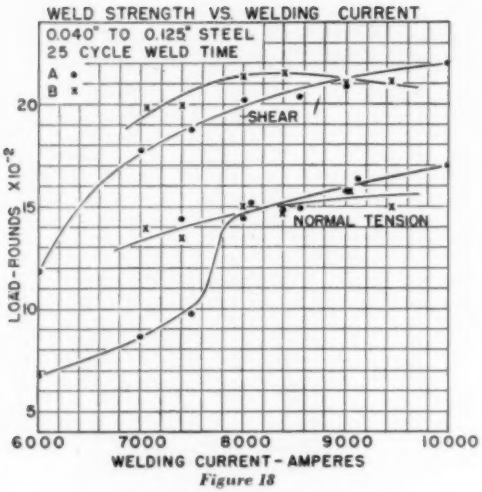


*Figure 18*

*Projection in 0.040-in. sheet*

(*A*) Diameter, 0.148 in.; height, 0.032 in.; electrode force, 450 lb.

*Projection in 0.125-in. sheet*

(*B*) Diameter, 0.148 in.; height, 0.026 in.; electrode force, 450 lb.

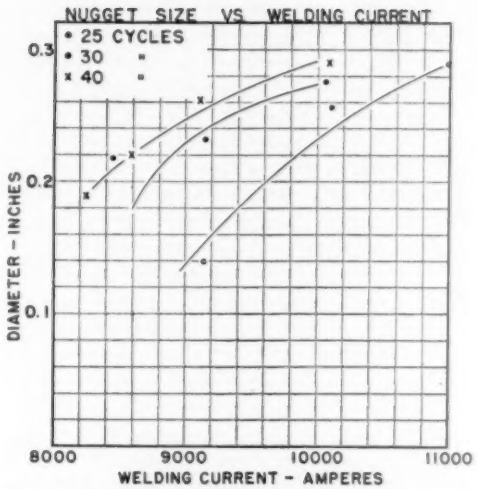


*Fig. 19 0.040 in. to 0.187-in. steel; projection in 0.040-in. sheet; projection diameter, 0.148 in.; projection height, 0.032 in.; electrode force, 450 lb.*

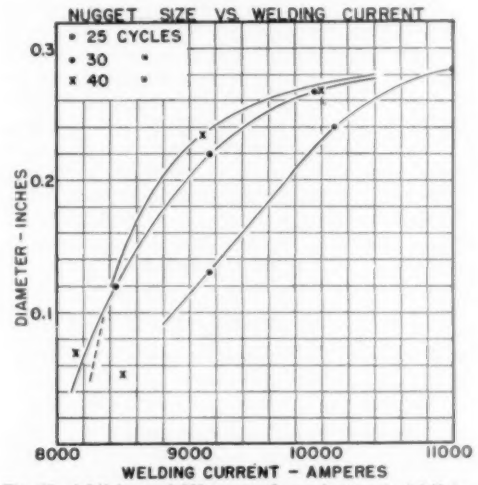


*Fig. 20 0.040 in. to 0.250-in. steel; projection in 0.040-in. sheet; projection diameter, 0.148 in.; projection height, 0.032 in.; electrode force, 450 lb.*

## WELDING 0.040-IN. STEEL TO 0.187-IN. AND 0.250-IN. STEEL

It was decided to restrict the electrode force to 450 lb. when welding the 0.040 in. to the 0.187 in. and 0.250 in. thicknesses because with the other thickness combinations nothing had been gained by increasing the electrode force. The 0.148 in. diameter, 0.032 in. height projection was placed only in the 0.040-in. sheet when welding these thickness combinations because it was believed that it was not too practical to punch small projections in steel 0.187 in. thick or thicker. However, if it is desired to place the projection in the thicker sheet the same welding conditions as with the projection in the 0.040-in. sheet can be used.

Welds were made at 25, 30 and 40 cycles weld time over a current range of 8000 to 11,000 amp. The nugget diameter versus welding current curves are plotted in Fig. 19 for the 0.040 in. to 0.187 in. thicknesses and in Fig. 20 for the 0.040 in. to 0.250 in. thicknesses. For both thickness combinations, an increase in weld time from 30 to 40 cycles resulted in only a small increase in weld diameter. Lengthening the weld time from 30 to 40 cycles effected a substantial increase in nugget penetration into the 0.187-in. sheet and just a small increase in penetration into the 0.250-in. sheet, but no change in penetration into the respective 0.040-in. sheets. In these cases the penetration into the 0.40-in. sheets was approximately 0.015 in., which was below the desired penetration of 50% of sheet thickness. At 10,000 and 11,000 amp. surface melting of the 0.040-in. sheet was evident around the projection.

**Table 6—Recommended Conditions for Welding 0.040 In. to 0.125-In. Steel**

| *Sheet with projection, in.* | *Projection, in.* | | *Electrode force, lb.* | *Time, cycles* | *Current range, amp.* |
|---|---|---|---|---|---|
| | *Diameter* | *Height* | | | |
| 0.040 | 0.148 | 0.032 | 450 | 25 | 8400–8800 |
| 0.125* | 0.148 | 0.026 | 450 | 25 | 8200–8800 |

* It is suggested that the projection be placed in the 0.125 in. sheet if design and other factors permit.

Shear and normal tensile specimens were welded in these thickness combinations using 450 lb. electrode force, 30 cycles weld time, and welding currents of 8000, 8500, 9000 and 9500 amp. These conditions were picked to give a nugget diameter of about 0.230 in. which is approximately the same as obtained when welding 0.040 in. to 0.062-in. steel or 0.040 in. to 0.125-in. steel using recommended conditions. This is based on the assumption that the strength of a weld between 0.040-in. steel and any thicker gage steel is directly proportional to the nugget diameter.

The results of the shear and normal tension tests are given in Table 7. Over the entire current range used, the shear strength for both thickness combinations did not vary greatly with current and was about the same as obtained with the other dissimilar thickness combinations welded under optimum conditions. However, the normal strength was much lower than that obtained with the other dissimilar thickness combinations. Furthermore the weld plug diameters, as measured from normal strength specimens, were smaller than the fused nugget diameters which were measured in etched specimens welded under identical conditions.

**Table 7—Results of Preliminary Tests of Welds in 0.040 In. to 0.187-In. Steel and 0.040 In. to 0.250-In. Steel**

| *Welding current, amp.* | *0.040 in. to 0.187 in. Shear strength, lb.* | *0.040 in. to 0.187 in. Normal strength, lb.* | *0.040 in. to 0.250 in. Shear strength, lb.* | *0.040 in. to 0.250 in. Normal strength, lb.* |
|---|---|---|---|---|
| 8000 | 2060 | 1030 | 1910 | 690 |
| 8500 | 2120 | 820 | 2000 | 800 |
| 9000 | 2220 | 1010 | 2080 | 770 |
| 9500 | 2060 | 1230 | 2210 | 810 |

These weld strengths were considered far from satisfactory and an attempt was made to obtain more favorable results. The low normal strength was attributed to the shallow weld nugget penetration; therefore, attempts were made to obtain greater penetration.

It will be recalled that at 10,000 amp. welding current, surface melting occurred at the projection on the

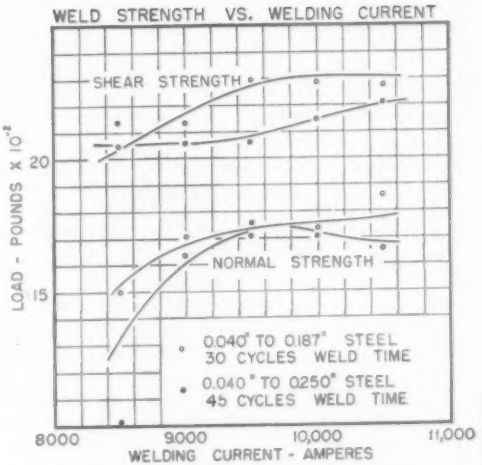


*Fig. 21 Electrode force, 450 lb.; projection diameter, 0.148 in.; projection height, 0.030 in.*

0.040-in. sheet restricting a further increase in current under these conditions. Up to this point, welds between dissimilar sheet thicknesses had been made using 28–30% conductivity electrode tip material, R.W.M.A. Group B, class 11 or 12, against both sheets. To reduce surface melting and thereby permit the use of higher welding currents, a higher conductivity electrode tip material, R.W.M.A. Group A, Class 2, was used against the 0.040-in. sheet. Using the same projection and electrode force, welds were made with 30 cycles weld time and currents of 10,000, 11,000 and 12,000 amp., and with 45 cycles weld time and 10,000 and 11,000 amp. There was no evidence of surface melting; however, expulsion occurred at 12,000 amp. weld current. At 30 cycles weld time and 11,000 amp. welding current, weld penetration into the 0.187-in. steel was about 0.130 in. with a nugget diameter of about 0.295 in. In this case penetration into the 0.040-in.

**Table 8—Recommended Conditions for Welding 0.040 In. to 0.187-In. Steel and 0.040 In. to 0.250-In. Steel**

| *Thickness combination, in.* | *Projection,* in. Diameter* | *Projection,* in. Height* | *Electrode force, lb.* | *Time, cycles* | *Current range, amp.* |
|---|---|---|---|---|---|
| 0.040–0.187 | 0.148 | 0.032 | 450 | 30 | 9300–10,300 |
| 0.040–0.250 | 0.148 | 0.032 | 450 | 45 | 9300–10,300 |

* In 0.040-in. sheet.

**Table 9—Recommended Conditions for Welding A.I.S.I. 1010, 1015 and 1020 Steel in Thicknesses from 0.010 to 0.125 In.**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Sheet thickness, in. | 0.010 | 0.020 | 0.040 | 0.062 | 0.125 | 0.187 | 0.250 |
| Electrode force, lb. | 110 | 225 | 450 | 750 | 2000 | 3000 | 4000 |
| Forge force, lb. | ... | ... | ... | ... | ... | 5000 | 8000 |
| Weld time, cycles | 6 | 6 | 15 | 20 | 45 | 130* | 225* |
| Weld current range, amp. | 5000–5400 | 5200–5600 | 5700–6300 | 8400–8900 | 14,400–15,000 | 23,000–25,000 | 27,000–29,000 |
| Projection diameter, in. | 0.110† | 0.110† | 0.140 | 0.170 | 0.300 | 0.394 | 0.532 |
| Projection height, in. | 0.015 | 0.015 | 0.025 | 0.042 | 0.055 | 0.080 | 0.110 |
| Approximate diameter of fused zone, in. | 0.090 | 0.110 | 0.170 | 0.190 | 0.340 | 0.690 | 0.830 |
| Typical strength, A.I.S.I.-1010 steel { Shear, lb. | 205 | 440 | 1430 | 2090 | 6060 | 16,800 | 27,000 |
| Typical strength, A.I.S.I.-1010 steel { Normal, lb. | 135 | 320 | 650 | 1010 | 4675 | 15,600 | 21,500 |

* Welds in these thicknesses must be started with the forge electrode force applied or with a reduced weld current as described in this report, Tables 3 and 4.

† Annular projection, see reference 3.

Table 10—Recommended Conditions for Welding A.I.S.I. 1010, 1015 and 1020 Steel 0.040 In. to 0.040 In., 0.062 In., 0.125 In., 0.187 In. and 0.250 In.

| | | | | | |
|---|---|---|---|---|---|
| Thickness, in., welded to: | 0.040 | 0.062 | 0.125 | 0.187 | 0.250 |
| Electrode force, lb. | 450 | 450 | 450 | 450 | 450 |
| Weld time, cycles | 15 | 20 | 25 | 30 | 45 |
| Weld current range, amp. | 5700–6300 | 7800–8200<br>7600–8000* | 8400–8800<br>8200–8800† | 9300–10,300 | 9300–10,300 |
| Projection diameter, in. | 0.14 | 0.148 | 0.148 | 0.148 | 0.148 |
| Projection height, in. | 0.02 | 0.032<br>0.030* | 0.032<br>0.026† | 0.032 | 0.032 |
| Typical strength, A.I.S.I.-1010 steel { Shear, lb. | 1430 | 1950 | 2100 | 2120 | 2300 |
| { Normal, lb. | 650 | 1450 | 1530 | 1700 | 1700 |

* With projection in 0.062-in. sheet.
† With projection in 0.125-in. sheet.

sheet was about 50%. A weld time of 45 cycles was required to obtain equivalent penetration into the 0.040- to 0.250-in. combination at 11,000 amp. welding current.

Normal tension and shear strength specimens were welded with 30 cycles weld time for the 0.040- to 0.187-in. combination and 45 cycles weld time for the 0.040- to 0.250-in. combination. The results of these tests, over a current range of 8500 to 10,500 amp. and at 450 lb. electrode force are shown in Fig. 21. Over this current range there was not a large variation in weld strength, except at 8500 amp. for the normal strength of the 0.040- to 0.250-in. combination.

The recommended conditions for welding 0.040 in. to 0.187-in. steel and 0.040 in. to 0.250-in. steel are given in Table 8 and are included in Table 10 for comparison with other thickness combinations.

## DISCUSSION

### *Welding 0.187 In. to 0.187 In. and 0.250 In. to 0.250 In.*

It was found necessary when welding the thicker gages of steel, 0.187 and 0.250 in., to utilize a forge force at the end of the weld current to minimize weld porosity. Using a forge force at the end of the weld, rather than a very high electrode force for the entire weld, reduced the welding current necessary to make a weld.

Most projection welding machines with a current capacity capable of welding 0.187- and 0.250-in. steel have a relatively heavy moving electrode head assembly. When the welding current begins to flow and the projection begins to soften, the electrode force on the projection is momentarily reduced because some of the force in the air piston is used to accelerate the moving head assembly to follow the projection collapse. This follow-up is further slowed down by friction in the head assembly slides. It was found that this point of low electrode force may be reduced by one of two methods. In one method, the electrode force is increased at the beginning of the weld for a short time when the projection is collapsing most rapidly. In the other method, the weld current is reduced to a low current value at the beginning so that the projection is heated at a slower rate and therefore is collapsed more slowly.

It will be recalled that when welds made in the 0.187- and 0.250-in. steel were tested in normal tension, the usual type of weld failure was by pulling a plug from one sheet. When tested in shear the usual type of failure was by shearing through the center of the weld nugget. Just the opposite effect is found in welds in steels of slightly higher carbon content. This is because the low-carbon steel is considerably weaker in shear strength than in tensile strength, so that the normal tension specimens may fail by pulling a plug although the cylindrical area stressed in shear is greater than the circular area stressed in pure tension. The ductility of this steel, as evidenced by the high normal to shear ratio, reduces the stress concentration effect at the periphery of the weld. The shear-type specimens failed in shear across the weld nugget in all cases, except welds with very large diameter nuggets, because the section across the weld which failed was stressed primarily in shear. Since the steel was considerably weaker in shear than tension, the shear-type failure took place.

The dimensions of the projections used were not found to be extremely critical. For the 0.187- and 0.250-in. steel, a projection diameter of approximately 2.2 times the sheet thickness and a height of approximately 20% of the diameter was found to be satisfactory.

### *Welding 0.040 In. to Thicker Gages*

When welding 0.040-in. steel to thicker gages it was found that the projection dimensions and electrode force used for welding two thicknesses of 0.040-in. steel were satisfactory. However, it was necessary to increase the welding current and weld time as the thickness of the heavier sheet increased up to 0.250 in., the thickest gage investigated. In addition, on the 0.187- and 0.250-in. sheets it was necessary to change from a low conductivity to a high conductivity electrode tip against the 0.040-in. sheet to prevent overheating at the higher current values used.

The first series of strength-current weld specimens between 0.040- and 0.125-in. steel yielded several unusually low normal strength values. The diameters of the plugs pulled in these cases were the same as would be expected from considerably higher strength welds. Hydrogen embrittlement was immediately suspected because the steel of these specimens were more rusty than previously used, and therefore required a longer

pickling time in 50% hydrochloric acid. This longer pickling time allowed more time for atomic hydrogen to diffuse into the steel. In addition, the specimens were welded and tested in tension within about 3 hr. after pickling so that the hydrogen did not have time to diffuse out of the steel. To investigate this effect further, three groups of specimens were pickled in 50% hydrochloric acid for 10 min., washed in water and in acetone, dried and then immediately welded using 8500 amp. welding current, 25 cycles weld time and 450 lb. electrode force. One group was tested in tension immediately after welding, a second group was tested after being heated at 110° C. for 21 hr. and the third group was tested after remaining at room temperature for 128 days. The results were as follows.

| *Treatment before test* | *Normal tension strength, lb.* | *Plug diameter, in.* |
|---|---|---|
| None, tested immediately after welding | 755 | 0.288 |
| Heated at 110° C. for 21 hr. | 1560 | 0.297 |
| Held at room temp. for 128 days | 1495 | 0.259 |

These results indicate that hydrogen embrittlement can result from pickling for too long a time in a solution which will deposit hydrogen on the steel.

Some of the 0.125-in. specimens of these tests had grit-blasted surfaces while others had as-rolled surfaces. It was noticed that the grit-blasted specimens for a given set of conditions pulled a smaller plug and failed with a lower normal strength than the as-rolled specimens welded and tested the same. It is believed that this difference in strength is caused by the formation of an outer zone of pressure or recrystallization type weld on the smoother rolled surface and not on the rough grit-blasted surface.

## CONCLUSIONS

### *Welding 0.187 In. to 0.187 In. and 0.250 In. to 0.250 In.*

1. It was necessary to apply a high-electrode force at the end of the weld current time to prevent or minimize porosity. This forging force was approximately twice the electrode force during the weld time.

2. To prevent flashing of the projection at the start of the weld, it was necessary either to apply a forge force for a short interval at the beginning of the weld, or to start the weld current at a low value and increase it gradually to the final welding current value.

3. The projection dimensions were not extremely critical for welding these heavy gages. The recommended projection diameter was found to be approximately 2.2 times the sheet thickness, and the height, about 20% of the diameter.

### *Welding 0.040 In. to Heavier Gages*

1. Steel, 0.040 in. thick, could be welded to thicker gages of steel using the same projection dimensions and electrode force which were used to weld 0.040 in. to 0.040-in. steel.

2. With an increase in the gage of the thicker material, a larger welding current and a longer welding time were required.

3. When the projection was punched in the thicker sheet, the weld strength was more uniform over a given current range than when the projection was punched in the thin sheet.

4. Hydrogen embrittlement resulted from pickling for too long a time in a solution which deposited hydrogen on the surface of the steel.

## ACKNOWLEDGMENTS

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# Welded Joints Between Dissimilar Metals in High-Temperature Service

***Effect of time and temperature on the structural stability of welded joints between austenitic and ferritic material using austenitic electrodes***

*by R. W. Emerson and W. R. Hutchinson*

## INTRODUCTION

THE successful joining of dissimilar ferrous metals by metal-arc welding is an accomplishment of the last two decades. From a recent review of the literature on this subject in which 98 references were cited, only 12 were prior to 1940.[1] Of these 12, six were of German origin. In the past 16 years since the first literature references were cited, great strides have been made in the welding of dissimilar metals and the welding of hardenable steels using austenitic electrodes.

Of the many applications where austenitic electrodes have been used, their use in connection with the welding of dissimilar metals, and air-hardening steels for elevated temperature service is most intriguing.

Austenitic electrodes for the joining of carbon and low-alloy steels for boiler and pressure vessel construction was initiated in Germany in 1935 on a relatively large scale by the Krupp Steel Works. The initiation of this method of welding by Krupp was based on the thought that after welding, stress relieving or heat treatment was unnecessary. The ultimate outcome of this experience resulted in the replacement by Krupp of more than 50 from a total of approximately 90 boiler drums. Some of the drums developed leaks in the early stages of boiler operations. Results of these investigations prompted many customers who had boilers in various stages of construction and erection, to reject all drums welded with austenitic electrodes.[2] The above practice of austenitic welding was also recommended to the piping fabricators by Krupp, as a good method of welding pipe lines. The I. G. Farben power plant, Leverkausen, upon Krupp's recommendation in 1936, welded both their St 55.29 carbon steel (0.35–0.42% carbon) saturated steam piping and their FK 335 (1% chrome–½% moly) alloy steel superheated steam piping with 23% chrome–19% nickel austenitic steel electrodes. The high-carbon steel saturated steam piping developed leaks at the welded joints after several hundred hours of operation and all joints were subsequently replaced with a low-carbon manganese ferritic weld. The austenitic welds in the chrome-moly main steam piping, however, had been in service for 55,000 hr. as of the year 1945, and no difficulties had been encountered. This piping was operating at an average temperature of 935–950° F. and a pressure of 1850 psi.

In the past 10 or 15 years a considerable tonnage of austenitic electrodes has been used in the United States by the petroleum industry for the welding of hot oil transfer lines of the air hardening 5 to 9% chrome-moly steels and generally speaking this procedure has given quite satisfactory results. Only in the past 5 years have austenitic electrodes been given serious consideration in the welding of power-plant piping particularly from the standpoint of joining austenitic to ferritic superheater tubes and the joining of 2¼% chrome–1% moly steam piping to austenitic turbine piping.

Austenitic electrodes have been used to some extent, however, in the joining of titanium stabilized chrome-moly superheater tubes, and numerous austenitic joints have been made in the past 5 years in carbon steel boiler feed lines at locations of austenitic flow nozzles. The details of such a joint are shown in Fig. 1.

**DIAGRAMMATIC SKETCH OF WELD-IN TYPE FLOW NOZZLE FOR BOILER FEED PIPING**

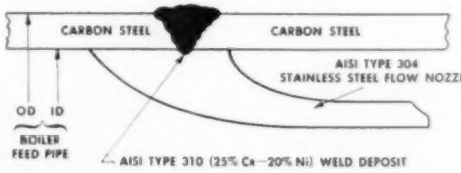


*Figure 1*

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Paper presented before the Thirty-Second Annual Meeting, A.W.S., Detroit, Mich., week of Oct. 15, 1951.

Many such joints are in service today operating at temperatures in the range of 400–450° F. and pressures as high as 2200 psi.

The joining of heavy wall 2¼% and 3% chrome–1% moly steam piping to austenitic Type 347 stainless turbine piping has, however, presented several major problems and has been the subject of numerous investigations.

Of particular note in this connection are two very excellent papers presented by Carpenter, Jessen, Oberg, and Wylie;[3] and Blaser, Eberle and Tucker,[4] at the annual meeting of the American Society of Testing Materials in 1950.

## SCOPE

At the time of inception of the research to be reported, it was considered that two major problems existed: namely (1) the effect of differential expansion between the austenitic and ferritic materials and the possibility of fatiguing action at the austenite-ferrite interface resulting from any possible cyclic temperature conditions either intentionally or unintentionally imposed; and (2) the effect of diffusion, and carbon migration from the ferritic to the austenitic material resulting from either or both postwelding heat treatments and service temperature.

The first of these two problems is essentially of a physical nature and in view of certain work being conducted at the time, and which has since been reported, on cyclic temperature testing of dissimilar metal joints,[5] it was decided to study the second problem which is fundamentally one of a metallurgical nature.

This paper therefore, covers the effect of time and temperature on the structural stability of welded joints between austenitic and ferritic materials using austenitic electrodes, with particular reference to carbon migration, depletion and recrystallization of the ferritic base metal at the austenitic weld metal interface and attending effects on the mechanical properties of such joints. Also covered is the relative carbide stabilizing effects of chromium, vanadium and titanium when present in the ferritic base metal and the effects of a vanadium-bearing weld deposit when used as a "buttering" on carbon, and chrome-moly materials before welding with austenitic electrodes.

## TEST PROCEDURE

Four 6 x 12 x ½-in., 3% chrome–1% moly steel test plates were given a 1550° F. normalize followed by a 1325° F. temper. An equal number of 6 x 12 x ½-in. austenitic Type 347 test plates were given a 2000° F. water quench, followed by a 1550° F. stabilize anneal. Each of the eight test plates were then beveled 37½° to the vertical along the 12-in. plate length. Each of the chrome-moly plates was welded to a stainless plate using in each case a different austenitic weld metal analysis. The chemistry of the 3% chrome–1% moly and 347 stainless test plates are given in Table 1. The nominal analysis used were: one, 19% chrome–9% nickel–columbium (Type 347); two, 18% chrome–12% nickel–2% moly (Type 316); three, 25% chrome–12% nickel (Type 309); and four, 25% chrome–20% nickel (Type 310). Future reference to the four test plates will be frequently made by number only. All plates were welded using ⅛- and 5/32-in. diameter reverse polarity d.-c. lime type electrodes. After welding from one side without backing, all plates were back-chipped and back-welded. Prior to welding, all chrome-moly plates were preheated to 400–500° F. After welding, each test plate was cut into two equal pieces. One piece of each of the four test plates was heated to 1350–1375° F. for 1 hr. and furnace cooled, and the other piece of each was heated to 1550° F. for 1 hr., furnace cooled to 1300° F., held 1 hr. at 1300° F. and furnace cooled. The former postweld heat treatment (1350–1375° F.) will be subsequently referred to as "heat treatment 'A'" and the latter as "heat treatment 'B.'"

A ½-in. slice was removed from each of the four test plates in each of two conditions of post weld heat treatment (A and B) and the balance of all plates were placed in a furnace and held for 3000 hr. at 1050 to 1100° F. followed by 2000 hr. at a temperature of 1150 to 1200° F. A ½-in. slice was removed from each test, however, at the end of 1500 hr. and 3000 hr. at 1050 to 1100° F. to check the macrostructure and hardness of the material.

Each plate was subsequently sectioned and the following test specimens removed:

1. Free-bend specimen.
2. Side-bend specimen.
3. Transverse 0.313-in. round tensile specimen.
4. Two 0.394-in. Charpy impact specimens.
5. Macro-specimen.
6. Micro-specimen.

For the purpose of contrasting the effect of carbon migration in low-carbon steel when welded with austenitic electrodes, two small ¼-in. thick test plates were welded comprising carbon steel to each of types 309 and 310 austenitic stainless steel. The electrodes used in each case were those having the same nominal composition as the stainless plate to which the carbon steel plate was welded. As-welded specimens from each of these tests were also heated in the same furnace, but after an elapsed time of 1500 hr. at 1050–1100° F.

**Table 1—Chemistry of Test Plates**

| Test plate | C | Mn | P | S | Si | Ni | Cr | Mo | Cb |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | % | | | | |
| 3% Cr–1% Mo | 0.14 | 0.50 | 0.025 | 0.025 | 0.42 | ... | 2.90 | 0.91 | .. |
| AISI Type 347 | 0.07 | 1.75 | 0.017 | 0.010 | 0.59 | 11.12 | 17.69 | .. | 0.93 |

## MECHANICAL PROPERTIES OF TEST WELDS AFTER 5000 HR. HEATING

Since the results of many tests, using austenitic electrodes to join austenitic to chrome-moly ferritic materials or to join low-carbon air-hardening chrome-moly materials together, have shown such a procedure to produce a joint, having adequate strength and ductility, no tests were made on the test plates immediately following the postweld heat treatments, with the exception of a hardness survey.

### *Side-Bend Tests*

Shown in Fig. 2 are side-bend specimens taken from each of the four test plates in each of two conditions of postweld heat treatment. It is to be noted that with the exception of three small defects in one of the specimens welded with 25–12 (test plate 3A), all specimens show reasonably good ductility as evidenced by their ability to withstand bending through 180 degrees. Further bending to an outside radius of $\frac{3}{4}$ in., resulted in the specimens "necking down" at the 3% chrome–1% moly-austenitic interface. Partial rupture occured at this location on two of the specimens (from test plates 1B and 4B), indicating weakness at this location.

*Fig. 2 Side-bend tests. 3% chrome – 1% moly plate (left) welded to A.I.S.I. 347 stainless steel plate (right) after 3000 hr. at 1050–1100° F., followed by 2000 hr. at 1150–1200° F. From top to bottom—tests 1, 2, 3, 4A; 1, 2, 3, 4B.*

### *Free-Bend Tests*

The free-bend tests are shown in Fig. 3 and the elongation obtained across the face of the welds is shown in

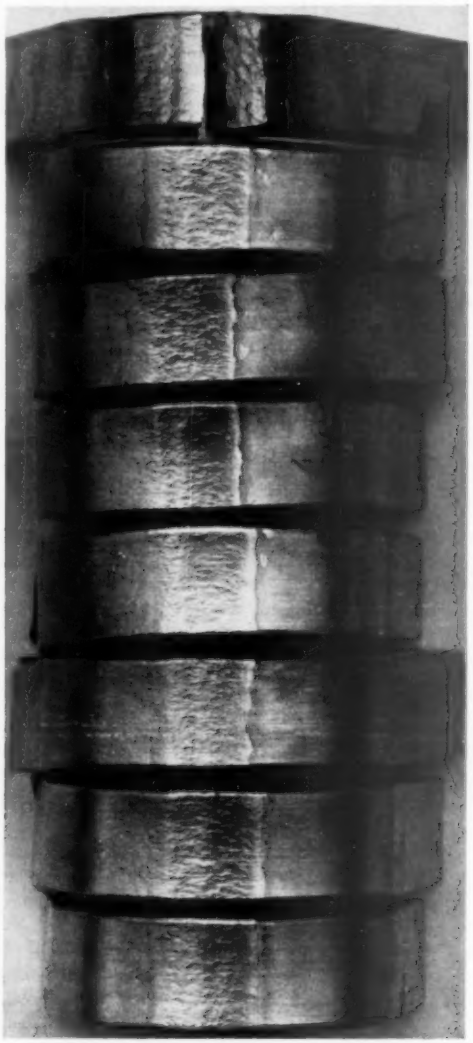


*Fig. 3 Free-bend tests. 3% chrome – 1% moly plate (right) welded to A.I.S.I. 347 stainless steel plate (left) after 3000 hr. at 1050–1100° F., followed by 2000 hr. at 1150–1200° F. From top to bottom, tests 1, 2, 3, 4A; 1, 2, 3, 4B. 1 ×*

**Table 2—Results of Free-Bend Tests**

AISI Type 347 stainless steel plate welded to 3% chrome–1% moly plate. Heated 3000 hr. at 1050–1100° F., plus 2000 hr. at 1150–1200° F.

| *Specimen No.* | *Welding electrode* | *Initial bending 180 deg. in jig % stretch* | *Continued bending to 1-in. outside radius % stretch* |
|---|---|---|---|
| A1* | 19–9 Cb | 18.0—fractured at 75-deg. angle | |
| A2 | 18–12–2 Mo | 20.5 | 26.9 |
| A3 | 25–12 | 18.5 | 25.3 |
| A4 | 25–20 | 20.0 | Complete fracture |
| B1† | 19–9 Cb | 17.0 | 21.0 |
| B2 | 18–12–2 Mo | 20.0 | 28.5 |
| B3 | 25–12 | 19.5 | Complete fracture |
| B4 | 25–20 | 18.0 | Complete fracture |

* Postweld heat treatment "A," 1350–1375° F. for 1 hr., furnace cool.

† Postweld heat treatment "B," 1550° F. for 1 hr., furnace cool to 1300° F. and hold 1 hr., then furnace cool.

Table 2. The test specimens were in reality forced to bend in the weld in so far as was possible by using a conventional welding jig for bending. With the exception of the one specimen welded with 19–9 Cb, which fracture at the line of fusion at a 75-degree bend angle, all other specimens withstood the 180-degree bend. Continuing the bending to an outside radius of 1 in. resulted in a complete fusion line fracture of three additional specimens and partial rupture of the remaining four specimens. All specimens exhibited fusion line failure along the path of potential decarburization. Shown in Fig. 4 is the fracture surface of one of the four completely fractured free-bend specimens which exhibits the contour of the individual weld beads as originally deposited.

### *Tensile Tests*

The results of the transverse round threaded subsize tensile tests (0.313 in. diameter x 1.4-in. gage length) are shown in Table 3. This test was negative in so far as revealing a plane of weakness at the transition from the austenitic to ferritic material. Since all failures occurred in the 3% chrome–1% moly base metal, this test indicates only the effect of the postweld heat treatment on the yield and tensile strength values as well as indicating that no embrittlement of the 3% chrome–1% moly material had taken place after 5000 hr. at temperature.

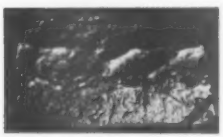


***Fig. 4 Fractured surface of one of four free-bend specimens which fractured along line of fusion showing contour of weld beads in 3% chrome–1% moly plate. 1.8 ×***

### *Results of Charpy Impact Tests*

Two Charpy impact specimens were removed from each test plate with the root of the notch placed as close as possible to the fusion line of the 3% chrome–1% moly base metal and stainless weld deposit. The results of the impact tests are shown in Table 4 together with three basic classifications of fracture as shown in Fig. 5. The first classification is that where the fracture goes essentially through the weld deposit as was the case in three of the four specimens welded

**Table 4—Results of Charpy Impact Tests***

AISI Type 347 Stainless Steel Plate Welded to 3% Chrome–1% Moly Plate. Heated 3000 Hours at 1050–1100° F. plus 2000 Hours at 1150–1200° F.

| *Specimen No.* | *Welding electrode* | *Charpy impact, ft.-lb.* | *Classification of fracture,* † |
|---|---|---|---|
| A1‡ | 19–9 Cb | 10.5 | 3 |
| A1 | 19–9 Cb | 26.0 | 2 |
| A2 | 18–12–2 Mo | 18.0 | 3A |
| A2 | 18–12–2 Mo | 17.5 | 3A |
| A3 | 25–12 | 20.0 | 1 |
| A3 | 25–12 | 27.0 | 1 |
| A4 | 25–20 | 10.0 | 3A |
| A4 | 25–20 | 17.0 | 3A |
| A | 347 base metal | 51.0 | .. |
| A | 3% chrome base metal | 42.5 | .. |
| B1§ | 19–9 Cb | 6.0 | 3 |
| B1 | 19–9 Cb | 8.0 | 3 |
| B2 | 18–12–2 Mo | 9.0 | 3A |
| B2 | 18–12–2 Mo | 34.6 | 2 |
| B3 | 25–12 | 13.0 | 3A |
| B3 | 25–12 | 28.0 | 1 |
| B4 | 25–20 | 14.0 | 2 |
| B4 | 25–20 | 15.0 | 3 |
| B | 347 base metal | 41.0 | |
| B | 3% chrome base metal | 35.0 | |

* ASTM Specification E23-41T-Specimen Type C.

† Classification of fracture: 1—Fracture predominantly through weld deposit. 2—Fracture through 3% chrome base metal, then paralleling line of fusion. 3—Fracture entirely along line of fusion. 3A—Fracture predominantly along line of fusion, then through weld metal.

‡ Postweld heat treatment "A," 1350–1375° F. for 1 hr., furnace cool.

§ Postweld heat treatment "B," 1550° F. for 1 hr., furnace cool to 1300° F. and hold 1 hr., then furnace cool.

**Table 3—Results of Tensile Tests**

AISI Type 347 stainless steel plate welded to 3% chrome–1% moly plate. Heated 3000 hr. at 1050–1100° F., plus 2000 hr. at 1150–1200° F.

| *Specimen No.* | *Welding electrode* | *Yield point, psi.* | *Tensile strength, psi.** | *% elongation in 1.4 in.* | *Reduction of area %* |
|---|---|---|---|---|---|
| A1† | 19–9 Cb | 52,300 | 77,800 | 22.9 | 62.1 |
| A2 | 18–12–2 Mo | 55,250 | 80,250 | 24.3 | 58.7 |
| A3 | 25–12 | 53,600 | 79,100 | 24.3 | 62.1 |
| A4 | 25–20 | 53,600 | 78,450 | 24.3 | 59.3 |
| B1‡ | 19–9 Cb | 44,350 | 73,850 | 21.4 | 63.3 |
| B2 | 18–12–2 Mo | 44,450 | 72,900 | 25.0 | 64.8 |
| B3 | 25–12 | 45,100 | 73,850 | 24.3 | 62.9 |
| B4 | 25–20 | 45,100 | 73,200 | 23.6 | 62.5 |

* Failure in 3% chrome–1% moly base metal.

† Postweld heat treatment "A," 1350–1375° F. for 1 hr., furnace cool.

‡ Postweld heat treatment "B," 1550 for 1 hr., furnace cool to 1300° F. and hold 1 hr. then furnace cool.

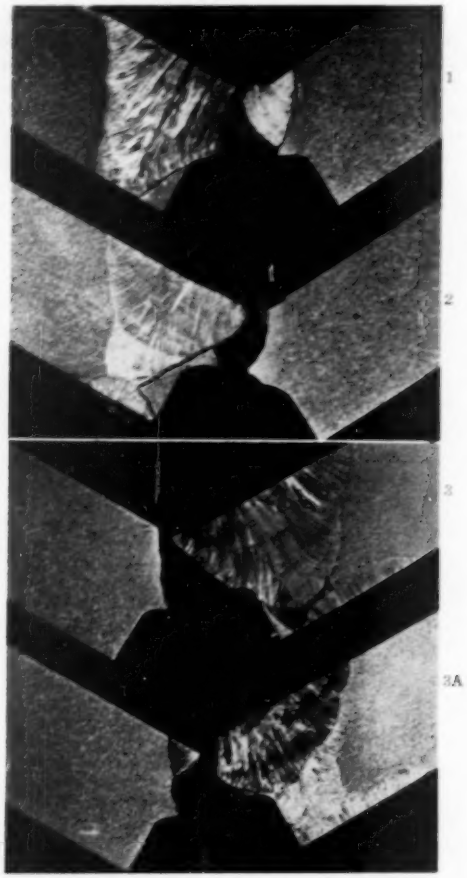



*Fig. 5 Charpy impact specimens showing different types of fracture as classified in Table 4. 2½ ×*

with 25–12 electrodes. In the specimens which fractured in this manner, the impact values range from 20 to 28 ft.-lb. The second classification is that where the fracture first occurs in the 3% chrome–1% moly base metal and then parallels the line of fusion. The values obtained on the three specimens exhibiting this type of fracture vary from 14 to 34 ft.-lb. From the specimens examined it appears that a larger fracture path occurred in the 3% chrome base metal for the specimen having the highest impact value. The third classification is that where the fracture path occurs entirely along the line of fusion. In some of the specimens the fracture occurred partially along the line of fusion and then followed into the last pass of deposited weld metal. This type of fracture is classified as 3A. It is to be noted that the fracture in all specimens which are typed as 3 or 3A, have their origin along the line of fusion. From Table 4 it is to be noted that the impact values on all such specimens do not exceed 18 ft.-lb.

It is to be further noted that the average impact values for the five "A" specimens classified as 3 or 3A, is 15 ft.-lb. as against an average of only 10 ft.-lb. in the "B" specimens. This places emphasis on maintaining a low stress-relieving temperature to prevent carbide migration during this operation and is in confirmation of the work of Carpenter *et al.* Shown in Figs. 6 and 7 are photomicrographs of two of the impact

*Fig. 6 Impact fracture through carbon depleted area of 3% chrome – 1% moly material. Specimen B4. Etchant 10% NaCN and 2% Nital. 100 ×*

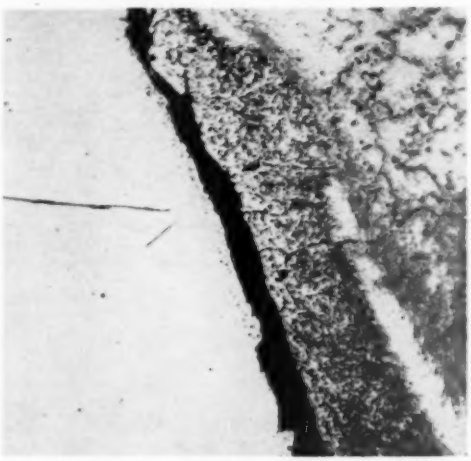


*Fig. 7 Impact fracture through carbon depleted area of 3% chrome – 1% moly material adjacent to line of fusion. Specimen A4. Etchant—10% NaCN and 2% Nital. 500 ×*

specimens exhibiting fracture through the carbon-depleted ferrite or adjacent to the ferrite at the interface with the austenite weld deposit.

Since the line of fusion is at an angle of 35–40 degrees with respects to the notch and not parallel to it, fracture along the line of fusion indicates weakness along this path with respect to the weld metal, since normal fracture would be through the weld metal parallel with the notch in all specimens. The results given in Table 4 indicates that specimens which fractured through the line of fusion have a notch toughness of only one-half to one-sixth that of the 3% chrome–1% moly base metal.

## HARDNESS SURVEY

Since a change in hardness of a given material would reflect a change in the metallurgical structure of the material, a hardness survey was made on all weld deposits both before and after aging for 5000 hr. This is presented in Fig. 8. The average hardness of the weld deposits was plotted together with that of the 3% chrome–1% moly plate in order to contrast the differences in weld metal hardness with that of the base metal as well as to determine whether any significant changes in hardness occurred as a result of the aging treatment. In general it was found that the weld metal hardness of the tests given the 1350–1375° F. treatment ("A" Specimens) was slightly higher than those given the 1550° F. treatment ("B" Specimens). The hardness of the aged specimens was also observed to be slightly higher than the respective specimens prior to aging.

For a given weld metal analysis, however, changes in hardness, due either to aging or to differences in postweld heat treatment, were found to be minor and believed to be of little significance. Considering the specimens which received treatment "A", the two specimens (A1 and A4) in which the largest difference in hardness has occurred with respect to the 3% chrome–1% moly base metal were those which fractured in bend testing. This same pattern did not follow, however, in the case of the "B" specimens.

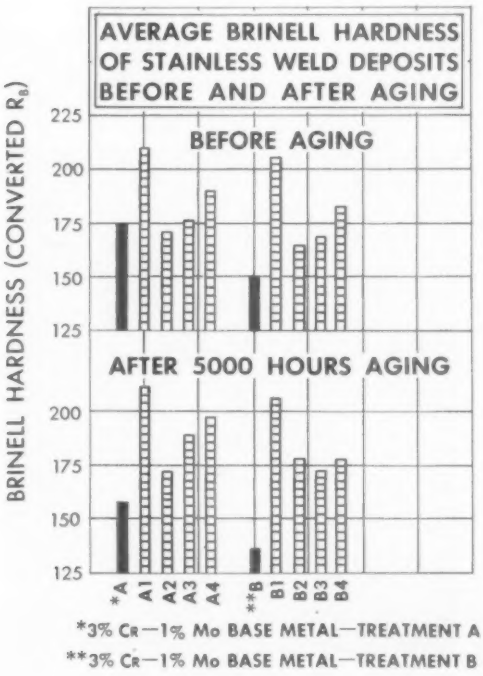



*Figure 8*

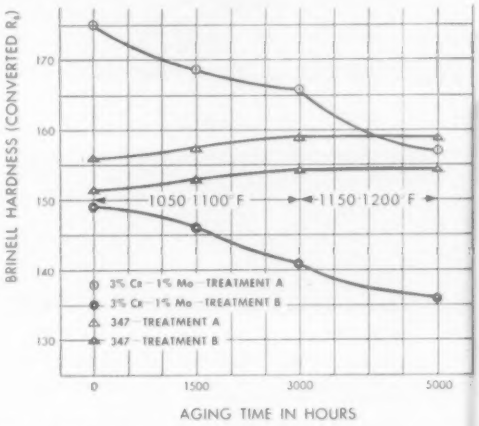


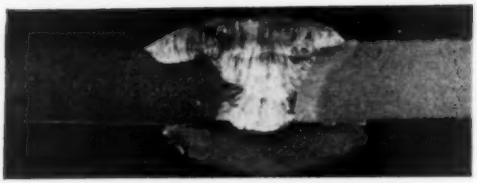

*Fig. 9 The effect of aging time and temperature on the Brinell hardness of 3% Cr-1% Mo steel and AISI 347 austenitic steel*

Shown in Fig. 9 is the effect of aging time and temperature on the hardness of 3% chrome–1% moly and 347 base metals welded. From this figure it is to be noted that a gradual softening of the 3% chrome–1% moly material has occurred while a slight but noticeable increase in hardness has occurred in the 347 stainless material. Also of particular interest is the fact that the normalized and tempered 3% chrome–1% moly plate had a higher hardness than the same plate when annealed, and although softening occurred upon aging, the difference in hardness between the normalized and tempered and annealed material is essentially the same after aging as before aging.

## METALLOGRAPHIC OBSERVATIONS OF TEST WELDS BEFORE AND AFTER 5000 HR. HEATING

The examination of the austenitic to carbon steel specimens, to which previous reference was made, was limited principally to metallographic observations both before and after long-time heating, since the aging temperatures involved were from 200 to 300° F. above that which carbon steel would normally be used.

(A) 309 Weld

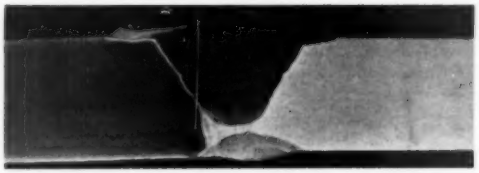


309 plate — Carbon steel plate

(B) 310 Weld

347 plate — 3% Cr – 1% Mo plate

(C) 310 Weld

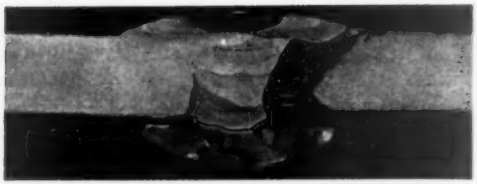


3% Cr – 1% Mo plate — 347 plate

***Fig. 10 Welds between dissimilar metals prior to aging***

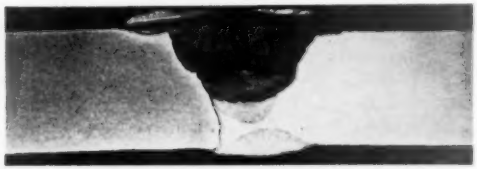
(A) As-welded condition. 2 ×. (B) Postweld heat treatment "A." 1.8 ×. (C) Postweld heat treatment "B." 1.8 ×

Shown in Fig. 10 are polished and etched sections of (*A*) Type 309 stainless plate, welded to carbon steel using Type 309 stainless electrodes in the as-welded condition and (*B*) and (*C*) Type 347 stainless, welded to 3% chrome–1% moly steel using Type 310 stainless electrodes having postweld heat treatments "A" and "B" (test plates 4A and 4B), respectively.



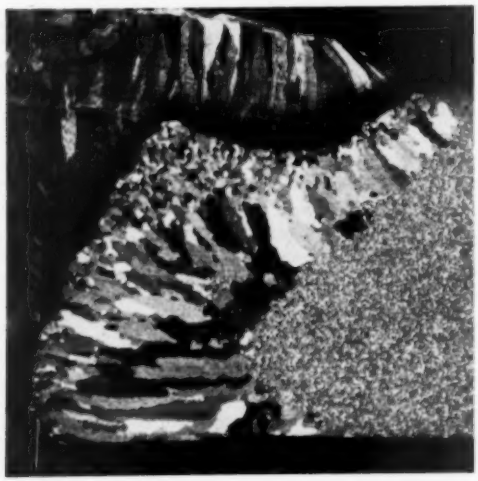
(A) Same as Fig. 10 (A) after aging 1500 hr. at 1050–1100° F., followed by 2000 hr. at 1150–1200° F. 2 ×

(B) Same as Fig. 10 (B) after aging 3000 hr. at 1050–1100° F., followed by 2000 hr. at 1150–1200° F. 1.8 ×



(C) Same as Fig. 10 (C) after aging 3000 hr. at 1050–1100 ° F., followed by 2000 hr. at 1150–1200° F. 1.8 ×

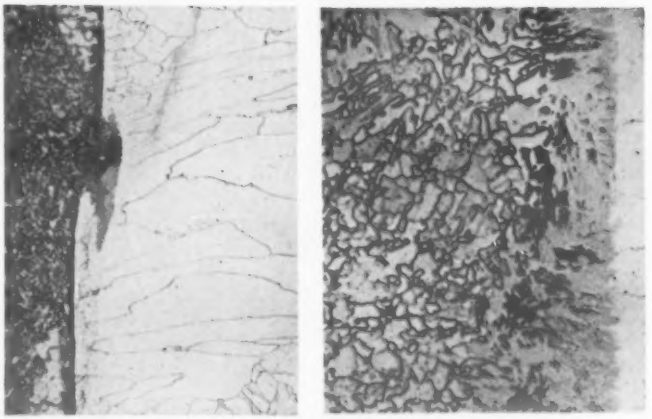
***Fig. 11 Welds between dissimilar metals after aging***



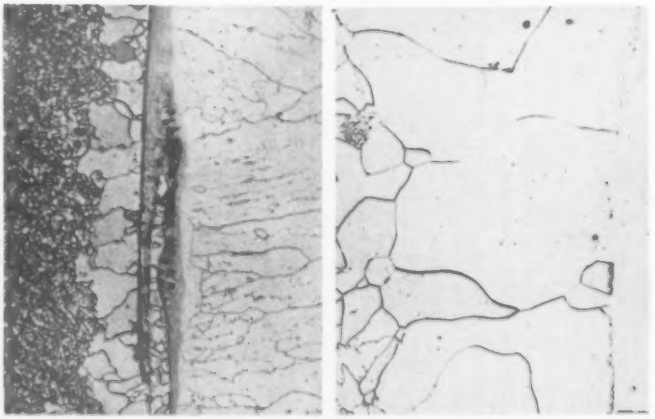
(A) Same as Fig. 11 (A). 8 ×

(B) Same as Fig. 11 (C). 8 ×

***Fig. 12 Aged specimens of Fig. 11 at higher magnification***

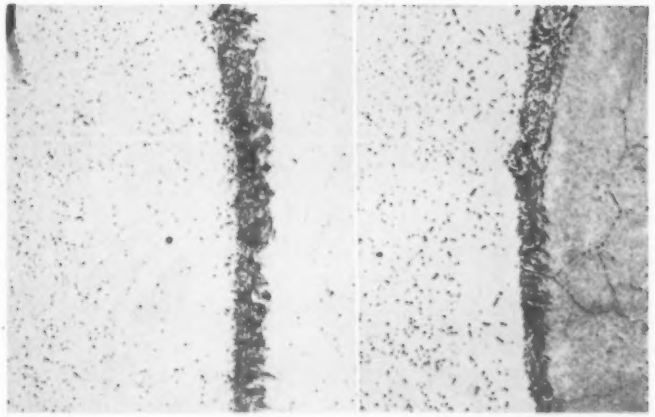


100 × Treatment "A" 500 ×

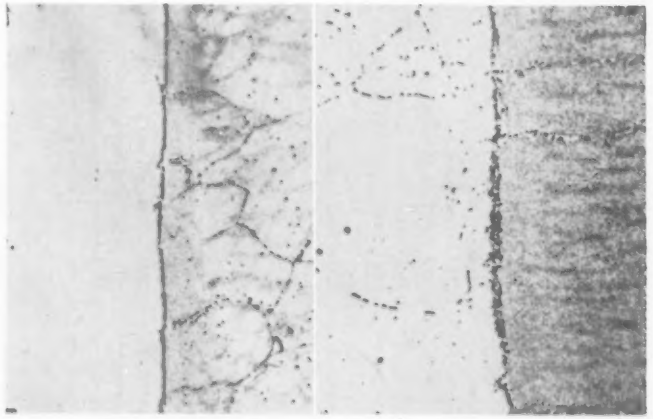


100 × Treatment "B" 500 ×

*Fig. 13 The effect of postweld heat treatment on grain growth and decarburization of 3% chrome – 1% moly base metal (left) at austenitic (25% Cr – 20% Ni) weld metal interface. Etchant—picric and hydrochloric acids in alcohol*



"A" treatment—before aging "A" treatment—after aging 5000 hr.



"B" treatment—before aging "B" treatment—after aging 5000 hr.

*Fig. 14 General carbide distribution at 3% chrome – 1% moly base metal (left) Austenitic (25% Cr – 20% Ni) weld metal (right) Interface. Etchant—Boiling alkaline potassium ferricyanide. 500 ×*

In contrast to Fig. 10 is Fig. 11 which indicates the effect of 3500 and 5000 hr. aging on the carbon steel to stainless, and 3% chrome–1% moly to stainless weldments, respectively. Two of the specimens of Fig. 11 are shown in Fig. 12 at a magnification of 8 ×. The heavy concentration of carbon within the weld and following the line of fusion together with the recrystallization and formation of long columnar carbon-free ferrite grains in the carbon steel base metal, clearly indicates the relatively high rate of diffusion of carbon in carbon steel at elevated temperatures when fused to high-chromium iron or steel. In sharp contrast to this is Fig. 12 (*B*) which shows only a trace of recrystallization and decarburization in the 3% chrome–1% moly steel although this specimen was heated to 1550° F. for 1 hr. as a postweld heat treatment plus an additional 1500 hr. at 1050–1100° F. which the specimen in Fig. 12 (*A*) did not receive.

The carbide stabilizing influence of 3% of chromium is believed to be quite evident, therefore, from the photographs of Fig. 12.

The microstructural pattern developed in specimens at the 3% chrome–1% moly austenitic weld interface as a result of differences in postweld heat treatment, both before and after aging, was found to be quite consistant and is illustrated in Figs. 13 and 14. The specimens which were given the 1375° F. postweld treatment "A" did not coarsen materially in the 3% chrome–1% moly material at the line of fusion although there were occasional small patches where grain coarsening had taken place. The specimens which were given the 1550° F. postweld heat treatment "B" did, however, develop quite generally a coarse grain band adjacent to the line of fusion. Both conditions are shown in Fig. 13 at 100×. It was also observed that where grain coarsening had occurred, decarburization had also occurred in the 3% chrome–1% moly material, the carbon having migrated and diffused into the austenitic weld deposit. Where grain coarsening had not occurred at the line of fusion, carbides were found to be present in the 3% chrome–1% moly material directly adjacent to the line of fusion. Both conditions are shown in Fig. 13, at 500×. Of the four test plates welded, it was noted that the one welded with the 347 electrodes had a somewhat greater tendency toward coarsening in the 3% chrome–1% moly base metal than did those welded with the other electrodes. This was particularly noticeable in the specimen given postweld treatment "A."

The general carbide distribution between the 3% chrome–1% moly base metal and austenitic weld metal is shown in Fig. 14 as it was found to occur in specimens given the "A" and "B" postweld heat treatments both before and after aging for 5000 hr.

Of the two postwelding heat treatments, it may be noted that treatment "A" did not result in any appreciable carbon migration as evidenced by the presence of scattered carbides in the 3% chrome–1% moly base material and lack of carbon migration into the austenitic weld deposit. The temperature of treatment "B," however, was sufficiently high to produce exaggerated grain growth and rapid decarburization in the 3% chrome–1% moly material adjacent to the line of fusion and carburization of the austenitic weld deposit as shown by the carbide-free base metal and the "cloudy" appearance of the weld adjacent to the fusion line. The specimens after aging show considerable carburization of the weld, as evidenced by the extreme "cloudiness" of the weld deposit. Also of interest is the fact that after 5000 hr., some grain boundary carbides are present in the coarse grain area of the "B" specimens adjacent to the line of fusion. These carbides are present, obviously, as a result of continued migration and depletion of carbon from the base metal.

The marked stabilizing effect of chromium on carbon migration becomes quite evident when contrasting Figs. 13 and 14 with that of Fig. 15. The carbon-free

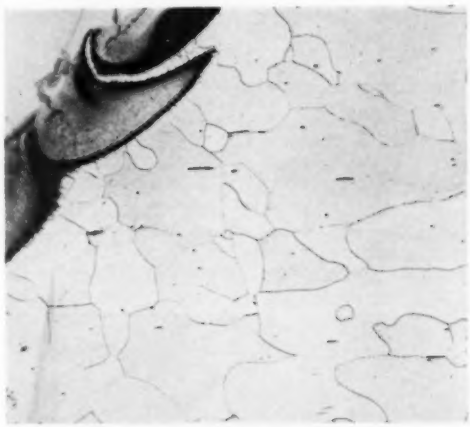


*Fig. 15 Weld deposit (upper left), line of fusion and large carbon-free ferrite grains in carbon steel after 3500 hr. at elevated temperature. Etchant—2% nital. 100 ×*

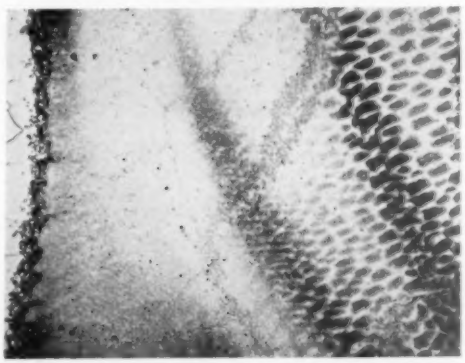
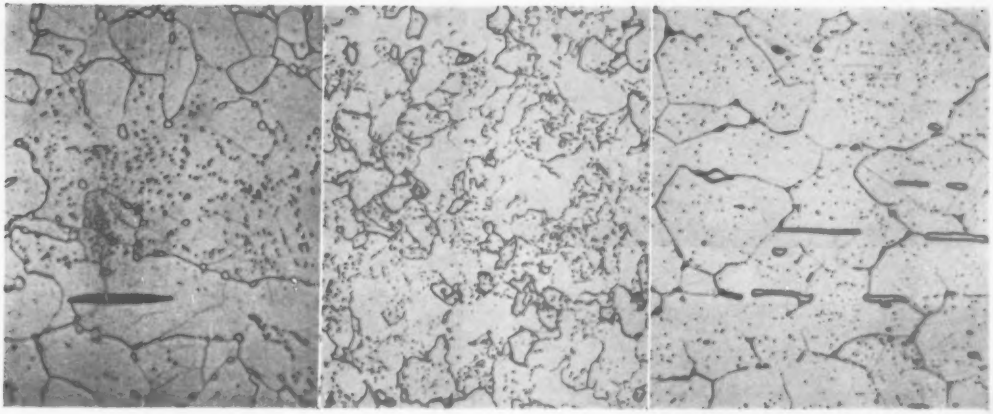


*Fig. 16 Carbon-free base metal (extreme left) and heavy concentration of carbon in 25% Cr – 20% Ni weld deposit. Etchant—Electrolytic 2% nital. Reduced one-third in reproduction. 500 ×*



(A) (B) (C)

(A) Mild steel after 3500 hr. aging. Etchant—2% nital. (B) 3% chrome–1% moly steel after 5000 hr. aging—treatment "B." Etchant—picric and hydrochloric acids in alcohol. (C) A.I.S.I. Type 347 stainless steel after 5000 hr. aging—treatment "A." Etchant—electrolytic 10% chromic acid

*Fig. 17 Microstructure of plate materials after aging. 500 ×*

ferrite of the carbon steel and the heavy concentration of carbon in the austenitic (25% Cr–20% Ni) weldment are quite apparent in Figs. 15 and 16. The grain growth in the carbon steel is approximately 50 times that found in the 3% chrome–1% moly steel and the concentration of carbon in the weld deposit considerably heavier than that found in similar welds adjacent to 3% chrome–1% moly material.

The microstructure of three of the plate materials used in this investigation is shown in Fig. 17 after aging. Of particular note is the complete spheroidization of the carbon steel (*A*) and the presence of sigma (dark constituent) at the grain boundaries of the austenitic material (*C*).

## THE EFFECT OF CARBIDE STABILIZING ELEMENTS ON CARBON MIGRATION

The second phase of this research deals with the stabilizing effects of vanadium and titanium on the migration of carbon across the base metal-weld metal interface of welded joints in carbon and alloy steels using austenitic electrodes. This work is, in effect, a confimation of the work of Carpenter and co-workers.

### *Test Procedure*

In making this study, four full size welded pipe joints were made as follows:

*Test Joint No. 1.* Two pieces of 8⅝ in. O.D. x 1⅛-in. wall 2¼% chrome–1% moly pipe were machined with a standard 22½ degree "U" bevel. The beveled end of one of the pieces was preheated to 400° F., a 1% molybdenum–0.2 vanadium steel "buttering" applied and the bevel remachined. The final weld was then preheated and welded with 1/8- and 5/32-in. diameter lime-type 347 electrodes.

*Test Joint No. 2.* One piece each of 8⅝ in. O.D. x 1⅛-in. wall 2¼% chrome–1% moly pipe and one piece of the same size of 1% chrome–1% moly–0.2 vanadium pipe was beveled as in Test Joint No 1, preheated to 400° F. and welded using 1/8- and 5/32-in. diameter lime-type 310 electrodes.

*Test Joint No. 3.* One piece of 5½ in. O.D. x 9/16-in. wall stabilized 5% chrome–½% moly pipe was machined on each end with a standard 37½-degree straight bevel. Two pieces of 1% chrome–½% moly pipe of the same size were beveled on one end only. The three pieces of pipe were so assembled as to produce two joints, one of which was welded with lime-type 310 and the other with low-hydrogen 2¼% chrome–1% moly electrodes. The electrodes sizes and preheat temperature was the same as used in Test Joints Nos. 1 and 2.

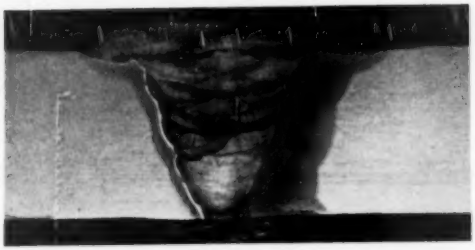
*Test Joint No. 4.* Two pieces of 6⅝ in. O.D. x 9/16-in. wall, A106, Grade B carbon steel were machined with a standard 37½-degree bevel. One of the two bevels was "buttered" using 1% moly–0.2 vanadium steel electrodes and rebeveled. The final weld was made using 1/8- and 5/32-in. lime-type 347 electrodes.

Each of the four test welds were longitudinally saw cut into numerous slices and specimens from each test weld were heated to 1200, 1350 and 1500° F. for 24 and 48 hr. One specimen from each test weld was heated to 1350° F. for 4 hr. All specimens were subsequently ground and polished through 3/0 metallographic paper and the apparent decarburization (width of exaggerated grain growth) measured at 25 diameters magnification.

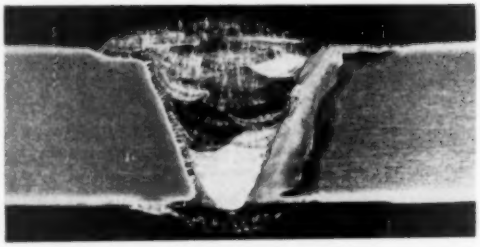
## DISCUSSION OF TEST RESULTS

Three macro-sections of each of Test Joints 1, 2, 3 and 4 are shown, respectively, in Figs. 18, 19, 20 and 21. Shown in each figure are the test welds in (*A*) the as-

(*A*) As-welded



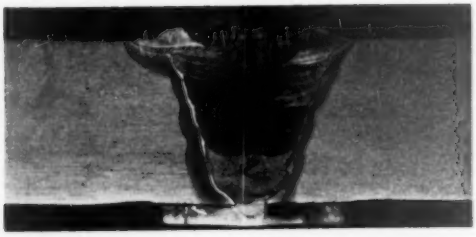
(*B*) 1350° F.; 48 hr.



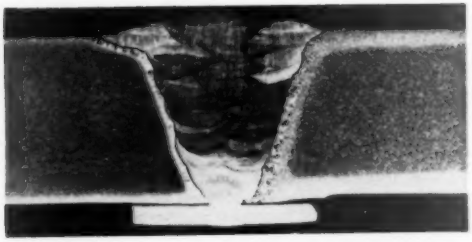
(*C*) 1500° F.; 48 hr.

*Fig. 18 Test No. 1—8⅝ in. O.D. x 1⅛-in. wall 2¼% chrome – 1% moly pipe welded with Type 347 stainless steel electrodes. Right-hand pipe bevel was "buttered" using 1% moly – 0.2% vanadium steel electrode prior to making final weld. 1 ×*

(*A*) As-welded



(*B*) 1350° F.; 48 hr.

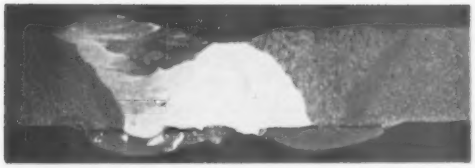


(*C*) 1500° F.; 48 hr.

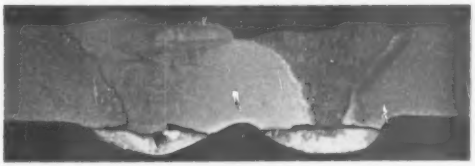
*Fig. 19 Test No. 2. 8⅝ in. O.D. x 1⅛-in. wall 2¼% chrome – 1% moly (left) welded to 1% chrome – 1% moly – 0.2% vanadium steel pipe (right) Using Type 310 stainless steel electrodes. 1 ×*

welded condition, (*B*) after heating at 1350° F. for 48 hr. and (*C*) after heating at 1500° F. for 48 hr.

The extent of grain growth in the base materials adjacent to the welds is believed to be quite apparent in the specimens shown in Figs. 18 through 21. It is to be noted that grain growth has occurred in the 2¼% chrome–1% moly material adjacent to the weld in Fig. 18 (*B*) whereas it has not occurred in the moly-vanadium "buttering" on the opposite side of the weld. Grain growth is likewise shown in the 2¼% chrome–1% moly material in Fig. 19 (*B*) whereas no evidence of this phenomenon is noted in the chrome-moly-vanadium material on the opposite side of the weld. Referring to Fig. 19 (*C*) however, it is to be noted that the grain growth in the chrome-moly-vanadium material is greater than that of the 2¼% chrome–1% moly material on the opposite side of the weld. It is also apparent that decarburization has occurred in the chrome-moly-vanadium material beyond the area of exaggerated grain growth. Close metallographic observation revealed that grain growth was not necessarily a prerequisite to carbon migration and that the latter did occur without respect to the former. Where columnar grain growth was found to occur however, decarburization appeared to be more sharply defined and less inhibited than where grain coarsening did not occur. In Fig. 20 (*C*) it is to be noted that considerable decarburization occurred in the 1% chrome –½% moly material at the austenitic weld interface although there is no evidence of this having taken place on the opposite side of the weld at the interfacy of the titanium stabilized 5% chrome–½% mole base metal. Since titanium has strong carbide-forming tendencies, the titanium present in the base metal was effective in preventing carbon migration from the base metal into the stainless weld deposit. When using materials containing carbide stabilizing elements, however, care must be exercised to avoid the presence of such elements in excess of that required to stabilize



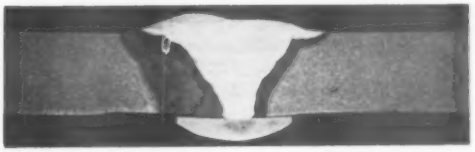
(A) As-welded



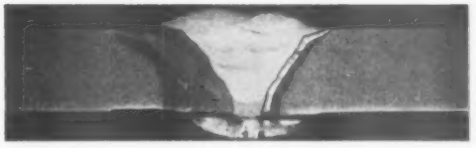
(B) 1350° F.; 48 hr.

(C) 1500° F.; 48 hr.

*Fig. 20 Test No. 3. 5"/16 in. O.D. x 5/32-in. wall 1% chrome – 1/2% moly steel pipe (Extreme ends) welded to 5% chrome – 1/2% moly – titanium pipe (Center) Using Type 310 stainless electrodes (left) and 2 1/4% chrome – 1% moly electrodes (right). 1 ×*



(A) As-welded



(B) 1350° F.; 48 hr.

(C) 1500° F.; 48 hr.

*Fig. 21 Test No. 4. 6"/16 in. O.D. x 5/32-in. wall carbon steel pipe welded with Type 347 stainless steel electrodes. Left-hand pipe bevel was "buttered" using 1% moly – 0.2% vanadium steel electrodes prior to making final weld. 1 ×*

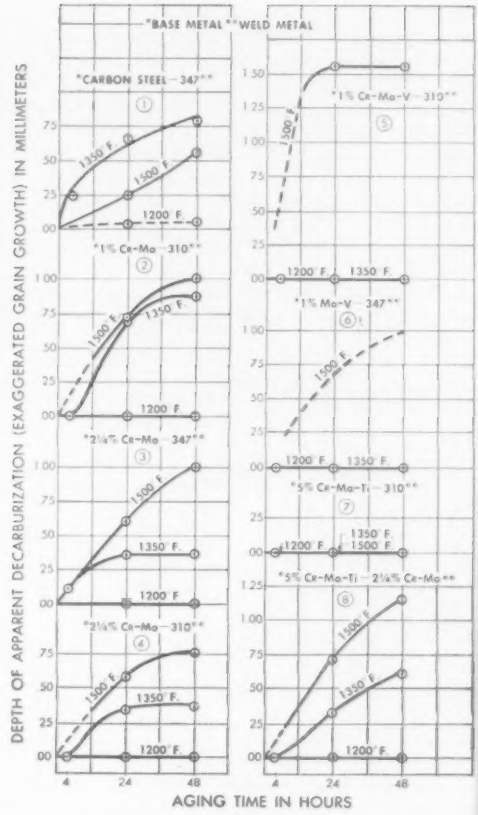

"BASE METAL" "WELD METAL
"CARBON STEEL – 347"
"1% Cr-Mo-V – 310"
"1% Cr-Mo – 310"
"1% Mo-V – 347"
"2¼% Cr-Mo – 347"
"5% Cr-Mo-Ti – 310"
"5% Cr-Mo-Ti – 2¼% Cr-Mo"
"2¼% Cr-Mo – 310"
1200° F.
1350° F.
1500° F.
DEPTH OF APPARENT DECARBURIZATION (EXAGGERATED GRAIN GROWTH) IN MILLIMETERS
AGING TIME IN HOURS

*Fig. 22 Apparent decarburisation in base metal at weld metal interface as a function of time and temperature (Note—item 8 decarburization in weld metal)*

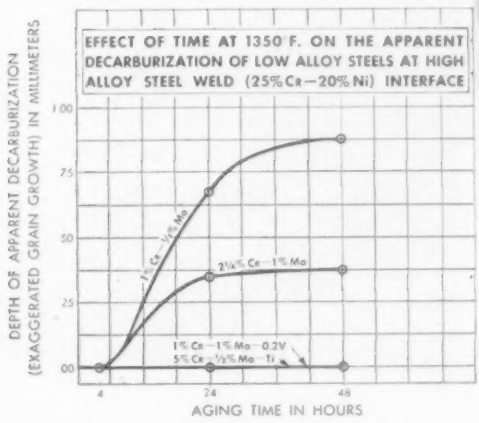

EFFECT OF TIME AT 1350° F. ON THE APPARENT DECARBURIZATION OF LOW ALLOY STEELS AT HIGH ALLOY STEEL WELD (25% Cr – 20% Ni) INTERFACE
1¼% Cr – ½% Mo
2¼% Cr – 1% Mo
1% Cr – 1% Mo – 0.2V
5% Cr – ½% Mo – Ti
DEPTH OF APPARENT DECARBURIZATION (EXAGGERATED GRAIN GROWTH) IN MILLIMETERS
AGING TIME IN HOURS

*Figure 23*

the carbon, if such materials are to be welded with electrodes which will produce weld deposits of relatively lower carbide-stabilizing power. Such was not the case at the titanium stabilized 5% chrome–$^1/_2$% moly base metal–2$^1/_4$% chrome–1% moly weld interface (Fig. 20 (*C*)), with the result that the titanium which was in excess of that required to stabilize the carbon in the 5% chrome–$^1/_2$% moly base metal caused carbon migration and decarburization of the less stable 2$^1/_4$% chrome–1% moly weld metal in an endeavor to satisfy the carbon requirements of the excess titanium present in the base metal.

Although no grain growth has occurred in the moly-vanadium "buttering" adjacent to the stainless weld in Fig. 21 (*B*), the narrow darkened line of fusion is indicative of carbon migration. In Fig. 21 (*C*) grain growth has occurred in large irregular patches in the moly vanadium "buttering" and the carbide-containing austenite at the line of fusion is clearly visible.

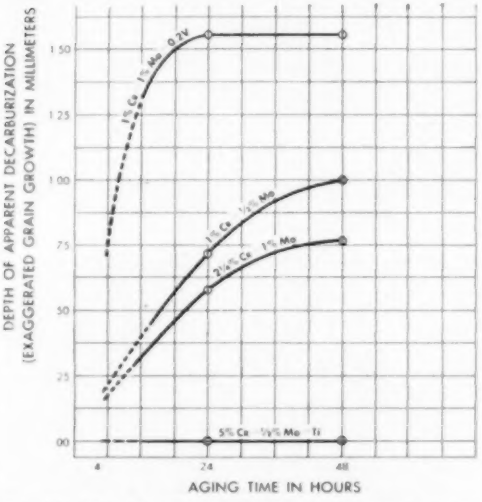
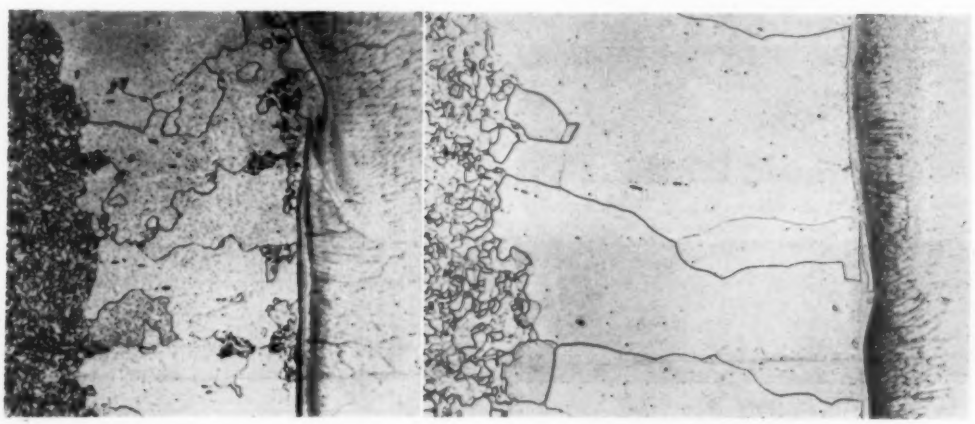



*Fig. 24 Effect of time at 1500° F. on the apparent decarburization of low-alloy steels at high-alloy steel weld (25% Cr-20% Ni) interface*

Plotted in Figs. 22 through 24 is the depth of apparent decarburization (exaggerated grain growth) of the various alloys investigated as effected by time and temperature. As was previously mentioned, carbon migration is not dependent on the occurrence of exaggerated grain growth; and decarburization may in some cases, therefore, be somewhat greater than shown in the plotted data. This data is believed, however, to indicate the relative carbide stabilizing effects of titanium and vanadium on the carbon in 1% and 2$^1/_4$% chrome-moly alloys when welded with austenitic chrome-nickel electrodes. From Fig. 22 it may be noted that the depth of decarburization of all of the alloy steels when measurable, increased with both time and temperature. The 1% chrome–$^1/_2$% moly material (Item 2) was decarburized to a greater degree than the 2$^1/_4$% chrome–1% moly steel (Item 4) for a comparable time and temperature. Vanadium effectively reduced decarburization of the 1% chrome–1% moly steel at 1350° F. although it was ineffective at 1500° F. Titanium was extremely effective in preventing carbon migration from the 5% chrome–$^1/_2$% moly steel (Item 7) but was likewise effective in promoting carbon migration from the relatively less stable carbides in the 2$^1/_4$% chrome–1% moly weld metal (Item 8).

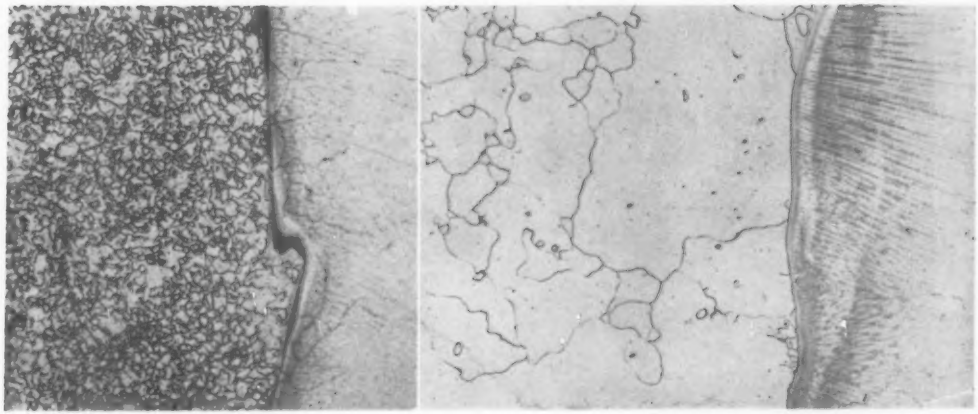
The effect of time at 1350 and 1500° F. on the apparent decarburization of chrome-moly alloys with and without the addition of vanadium and titanium, at the interface of a high chrome-nickel weld deposit is plotted respectively in Figs. 23 and 24.

From Fig. 23 it may be noted that decarburization is greater in the unstabilized chrome-moly alloys at 1350° F. than in those stabilized with vanadium and titanium.



(*A*) Heated 1350° F.; 24 hr. (*B*) Heated 1500° F.; 24 hr.

*Fig. 25 Grain growth and decarburization in 2$^1/_4$% chrome – 1% moly steel (left) adjacent to line of fusion and 25% chrome – 20% nickel weld deposit (right). 100 ×. Etchant—2% nital and boiling alkaline potassium ferricyanide*



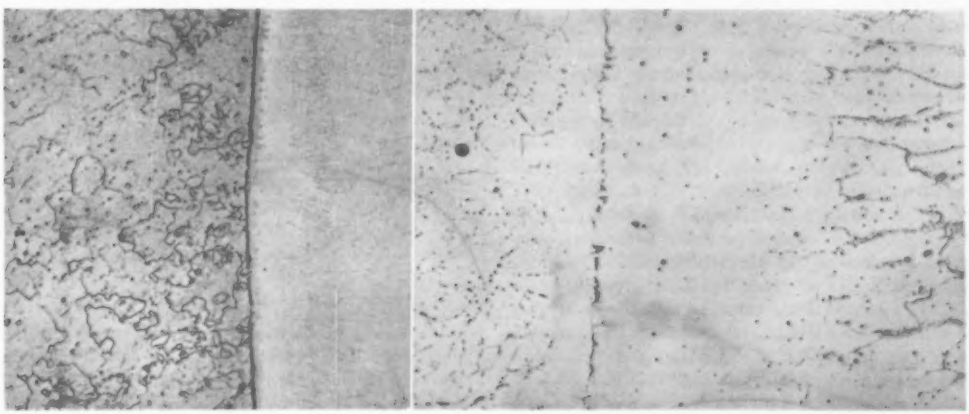
(A) Heated 1350° F.; 24 hr. (B) Heated 1500° F.; 24 hr.

*Fig. 26 Grain growth and decarburization in 1% chrome – 1% moly – 0.2% vanadium steel (left) adjacent to line of fusion and 25% chrome – 20% nickel weld deposit (right). 100 ×. Etchant—2% nital and boiling alkaline potassium ferricyanide*

At 1500° F., however, the vadanium stabilized material exhibited excessive decarburization while the titanium bearing 5% chrome–½% moly material gave no evidence of decarburization.

The grain growth and decarburization which occurred in the 2¼% chrome–1% moly steel and the 1% chrome –1% moly–0.2 vanadium material after heating for 24 hr. at 1350 and 1500° F. is shown, respectively, in Figs. 25 and 26. Carbides may be observed in the region of exaggerated grain growth in Fig. 25 (*A*) although decarburization is shown to be relativley complete in Figs. 25 and 26 (B). Due to the fine grain structure exhibited in Fig. 26 (*A*), the extent of decarburization is not readily visible. Carbon migration has occurred in this specimen as evidenced by the "cloudy" appearance of the carbide-containing austenite just inside the line of fusion similar to that exhibited in the other photomicrographs of Figs. 25 and 26. The titanium stabilized 5% chrome–½% moly base metal, line of fusion and 25–20 stainless weld deposit is shown in Fig. 27.

Whereas Fig. 24 indicated no decarburization of the titanium-stabilized base metal adjacent to the stainless weld deposit, microscopic observations indicated a slight concentration of carbides in the titanium-stabilized base metal and the complete absence of carbides in the weld deposit directly adjacent to the line of fusion, thus indicating slight but definite carbon migration in the direction of the base metal. Otherwise no noticeable change was observed in the microstructure of the base metal. Shown in Fig. 28



100 × (A) Heated 1500° F.; 24 hr. (B) 600 ×

*Fig. 27 Titanium stabilized 5% chrome – ½% moly pipe (left), line of fusion, and 25% chrome – 20% nickel weld deposit (right). Note carbon migration is in direction of titanium stabilized base metal. Etchant—(A) Boiling alkaline potassium ferricyanide and 10% nital; (B) electrolytic 10% chromic acid and 2% nital*

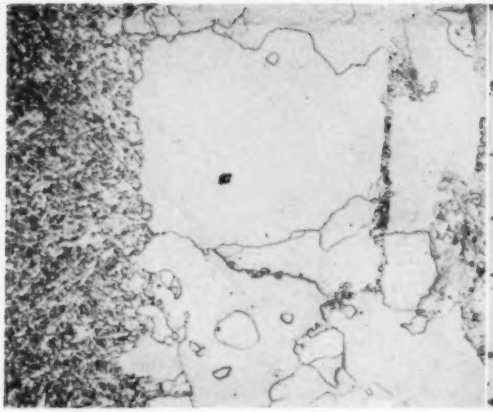


*Fig. 28 Grain growth and decarburization in 2¼% chrome–1% moly weld deposit adjacent to titanium stabilized 5% chrome–½% moly base metal. Specimen heated 1500° F.; 24 hr. Etchant—2% nital. 75 ×*

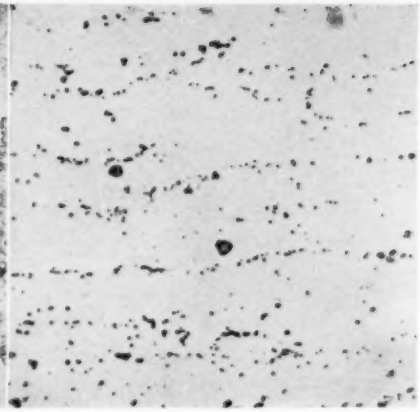


*Fig. 29 Concentration of carbides in titanium stabilized 5% chrome–½% moly pipe adjacent to decarburized 2¼% chrome–1% moly weld deposit shown in Fig. 28. Etchant—2% nital. 500 ×*

is the exaggerated grain growth and decarburization of the 2¼% chrome–1% moly weld deposit adjacent to the titanium stabilized base metal after heating for 24 hr. at 1500° F. The concentration of carbides in the base metal resulting from the decarburization of the weld metal is shown in Fig. 29. Since the carbides were found as stringers it is assumed that they are titanium carbides formed from the migration of carbon into a material containing titanium in excess of that required to stabilize the carbon present.

## CONCLUSIONS

1. Fractures occurred in slow-bend test specimens and impact-test specimens in the proximity of the 3% chrome–1% moly ferritic base metal–austenitic weld metal interface when tested after aging for 5000 hr. at elevated temperature.

2. Under the same conditions, conventional tension tests did not fracture in this location, but in the ferritic base metal.

3. The observed location of fracture is believed to have resulted essentially from the migration of carbon from the 3% chrome–1% moly base metal into the austenitic weld deposit.

4. The average impact strength as determined by Charpy tests was found to be lower at the austenitic-ferritic interface of test plates given a 1550° F. postweld heat treatment than in those given a 1350–1375° F. postweld treatment when tested after 5000 hr. at simulated operating temperatures, thus emphasizing the desirability of maintaining a low stress-relieving temperature after welding.

5. Metallographic observations quite consistently revealed the occurrence of exaggerated grain growth in the 3% chrome–1% moly base metal along the line of fusion in the specimens given the 1550° F. postweld heat treatment whereas this was only occasionally observed in the specimens given the 1350–1375° F. postweld heat treatment, with the one exception of the specimens removed from the test plate welded with 347 electrodes and stress relieved at 1350–1375° F.

6. Contrasting the carbon migration in carbon steel versus 3% chromium–1% molybdenum steel after 5000 hr. at elevated temperature, it is quite apparent that 3% of chromium has a considerable effect in stabilizing the carbides in the 3% chromium–1% molybdenum steel.

7. Short time tests at elevated temperature indicates both vanadium and titanium to have a beneficial effect on the carbide stability of low-alloy ferritic steel; the latter material being extremely effective.

8. Although the presence of strong carbide stabilizing elements in ferritic steels are effective in preventing carbon migration from such a material into a high chromium austenitic weld, care must be exercised to avoid the presence of such elements in excess of that required to stabilize the carbon, if such materials are to be welded with electrodes which will produce weld deposits of relatively lower carbide-stabilizing power.

9. Carbon migration is not dependent upon the occurrence of exaggerated grain growth but the rate of carbon diffusion appears to progress more rapidly in those instances where columnar grain growth was found.

## CONCLUDING REMARKS

As was previously mentioned, the work reported deals essentially with the problem of carbon migration across a low-alloy ferritic–high-alloy austenitic interface and is only one of the problems involved in making a welded dissimilar metal pipe joint which will give satisfactory service performance at elevated temperature.

Carbon migration in itself is not believed to be a serious problem. The rate of diffusion of carbon at

1050° F. is relatively slow and is believed to be of little significance. High-temperature postweld heat treatments, however, will result in rapid carbon migration and such treatments for any prolonged period of time would result in more carbon migration than would be obtained in many years at the service temperature. High-temperature postweld heat treatments are, therefore, to be avoided.

In placing dissimilar metal joints in service, excessive temperature cycling should be avoided, particularly when the high-temperature side of the cycle is in the scaling range of the low-alloy ferritic steel.

Dissimilar metal joints have, in the past, given quite satisfactory service and should continue to do so provided (1) excessive carbon migration has not been developed by high-temperature postweld heat treatments; (2) the operating temperature is relatively uniform; (3) the surface stability of the low-alloy ferritic material is adequate for the maximum service temperature.


## ACKNOWLEDGMENTS

The authors wish to express their gratitude for the assistance given by Matthew Morrow, William Gilson and Regis Rothrauff, of the Pittsburgh Piping & Equipment Co. metallurgical staff, for making many of the tests reported in this investigation.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# Investigation of Factors Which Determine Performance of Weldments

### *Discussion by R. H. Aborn*

The authors are to be congratulated on this very carefully planned and executed project and also for their clear presentation of a complex problem.

The lack of apparent correlation between relative Charpy impact-temperature characteristics and the explosion bulge tests, or between the relative flow strength characteristics and the explosion bulge tests, confirms once more that weld performance cannot be evaluated by a test which does not include both weld metal and heat-affected zone as well as the original base metal.

Certain aspects of this investigation appear to warrant somewhat more emphasis than the authors have given in the text of their paper. First, the entire investigation is based upon the testing of weldments which have been ground flush, thereby giving results which do not take into account the natural notch existing in most weldments. We suggest that this may be one of the principal factors explaining the differences observed in this investigation in contrast with the explosion tests reported recently by G. S. Mikhalapov.[1] The much closer approach of certain weldments to the performance of the prime plates in this work in contrast to the Mikhalapov tests is believed to be a demonstration of the importance of the natural notch. In this connection, one may inquire whether the tests of prime plates were carried to a sufficiently low temperature, inasmuch as the 1% criterion of brittle performance was apparently not reached at the lowest temperature of test, the lowest plotted strain being 3 to 4%.

Secondly, we suggest that the influence of microstructure is more important in controlling the net behavior of a weldment than appears to have been stated. For example, the strikingly different characteristics of the single pass submerged arc weld, previously reported,[2] demonstrates the importance of weld metal structure, as well as the structure of the adjacent base metal, for the submerged arc weld microstructures would differ greatly from the corresponding structures in the manually welded joints in this paper.

From the authors' thesis that weld metal is the controlling factor in the performance of weldments, one may reason that a flash-welded joint from which all of the weld metal has been removed, should equal the performance of the unwelded base metal. However, experience with such joints does not support this inference, and demonstrates the controlling influence of the heat-affected zone.

It is noted that the 6010 weld metal is the only case in which the same weld metal was both over- and under-matched, and its greater strain-aging susceptibility may be an important factor in its behavior when undermatched.

(*Continued on page 160-s*)


**Dr. R. H. Aborn** is Assistant Director of Research with the United States Steel Co., Kearny, N. J.



Paper by C. E. Hartbower and W. S. Pellini was published in the Research Supplement to the October 1951 issue of THE WELDING JOURNAL, pp. 499-s to 511-s.

# Stainless Clad Steels

***Review of published and unpublished information on manufacturing methods, carbon diffusion, physical and mechanical properties, heat treatments, welding procedures and processes, dilution, selection of welding electrodes and flame cutting***

*by Helmut Thielsch*

**Summary**

*Definition.* A *stainless clad steel* is a composite steel made up of a mild or low-alloy "backing" steel to which a stainless-steel cladding is continuously bonded over the entire contact area. The stainless-steel cladding generally amounts to about 10 to 20% of the total sheet or plate thickness.

*Manufacture.* Stainless clad steels are generally commercially produced by (1) roll welding, (2) casting, (3) intermelting, (4) arc and gas welding and other processes in which combinations of these are used. In these methods the final steel-mill operation usually consists of soaking a composite assembly at about 2100 to 2350° F. (1150 to 1290° C.) followed by hot rolling to the desired plate or sheet gage.

*Carbon Diffusion.* In stainless clad steels noticeable carbon diffusion may occur across the bond from the backing steel into the stainless cladding when the material is exposed to temperatures at which the diffusion rates of carbon in steel are appreciable. The use of intermediate layers of nickel or certain other alloy materials at the bond between the backing steel and the cladding may considerably inhibit such carbon diffusion which only in very severe cases has occasionally affected detrimentally the fabrication and service behavior of clad materials.

*Specification Requirements.* ASTM Specifications require that the tensile properties of the stainless clad plate (cladding along one side of the test bar) be equal to or greater than the minimum requirements prescribed for the base plate material alone. Moreover, two bend tests of the composite plate should also be made, one with the alloy cladding in tension and the other with the alloy cladding in compression. On sheets and strips less than $^3/_{16}$ in. thick the bend-test specimens must stand being bent cold with the clad side in tension through an angle of 180°—without cracking on the outside of the bent portion. On plates more than $^3/_{16}$ in. thick the purchaser may also require shear tests to show a minimum shear strength at the bond of 20,000 psi.

*Joining.* Stainless clad steels and applied liners generally are readily weldable. Certain factors, however, should be considered: (1) welding procedure, (2) welding position, (3) positioning and fit-up, (4) groove preparation, (5) plate thickness, (6) dilution and (7) selection of stainless electrodes.

Thin plates $^1/_8$ to $^1/_4$ in. in thickness are generally welded from both sides with stainless steel electrodes. Moreover, 80-degree V-joints are most commonly employed on the mild steel side.

Plates between $^1/_4$ and $^1/_2$ in. generally are welded by (1) tacking plates from base steel side with steel welding electrodes, (2) completing weld on base steel side with steel electrodes, (3) chipping at clad side of joint to remove any unfused area and (4) depositing on chipped groove the necessary number of weld beads or layers with a suitable stainless-steel electrode.

Plates heavier than $^1/_2$ in. generally are welded in a manner similar to the $^1/_8$- to $^1/_2$-in. plates. However, because the heavier plates are more susceptible to cracking as result of high restraint, special joints and welding procedures are sometimes necessary.

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This report was prepared under the auspices of the Literature Advisory Committee of the Welding Research Council. G. E. Doan, *Chairman*; T. S. Fuller, L. E. Grinter, C. E. Jackson, E. M. MacCutcheon, R. F. Miller, W. Spraragen, David Swan, R. David Thomas, Jr., J. L. Walmsley and Helmut Thielsch, *Secretary*.

## INTRODUCTION

A *STAINLESS clad steel* is a composite steel assembly in which a stainless steel is joined to a mild or low-alloy steel. Such a composite assembly is usually produced in the form of plates or sheets in which the stainless cladding is bonded on one or on both sides of the base (or backing) steel and is marketed as single clad or double clad, respectively. The stainless-steel cladding generally amounts to about 10 to 20% of the total sheet or plate thickness. These composite plates combine the desirable corrosion resistance of the stainless steel with the forming qualities of the mild or low-alloy base steel. Since corrosion resistance is provided at decreased cost,[44] these steels are frequently used for industrial purposes. This holds true particularly now because of the serious world-wide shortage of stainless steels which exists at this time.

Differentiation is generally made between two types of composite stainless steels: (1) the stainless clad steels and (2) the applied liners. In a *stainless clad steel* the stainless cladding makes a continuous bond with the base steel. In *applied liners* the stainless steel makes an intermittent (discontinuous) bond with the base steel over its entire surface.

Whereas *Stainless Clad Steels* are discussed in this review, *Stainless-Steel Applied Liners* are the subject of a subsequent article.

The choice of whether to use a solid stainless steel, a clad stainless steel or an applied liner depends not only upon the thickness of the plate needed but also upon many design and fabrication considerations as well as upon economic conditions.

Solid stainless-steel plates are generally used up to $^3/_{16}$ in. thickness.

From $^3/_{16}$ to $^1/_2$ in., solid stainless steel and stainless clad steels are competitive. If consideration is given only to the higher allowable stresses permitted in the solid stainless steels its use would be more economical.[74] However, where stiffness or rigidity are more important than tensile strength, as in storage tanks, processing tanks and similar vessels, clad steels may be more suitable than solid stainless steels. When higher strength steels (A-212 or A-204, for example) are used as backing steels instead of mild steels, the difference between the allowable stresses of the clad and solid materials is also reduced.[74] In high-temperature applications the solid austenitic stainless steels up to $^1/_2$ in. thick are generally preferred over comparable clad grades. On the other hand, under these conditions the straight chromium martensitic or ferritic stainless steels would be more advantageously used in the clad form than in the solid form.[74] When heat transfer is primarily considered the clad grades have a definite advantage over solid stainless-steel grades because of their better heat conductivity.[74] The overweight tolerances for solid stainless steels are somewhat in excess of the tolerances for clad grades. Hot-forming costs are consider-

ably higher for solid than for clad materials. In addition to these costs, annealing and pickling are not considered in the base price for solid materials but they are included in the base price for clad materials.[74] These factors may become quite important when the construction of a large vessel is under consideration.[74]

From 1/2 in. to 1 1/4 in. wall thickness, stainless clad steels and applied liners are competitive. The clad materials are generally preferred up to 3/4 in. whereas, above 3/4 in., lined materials are more commonly used. Above 1 1/4 in. the construction of lined vessels is usually most economical if operating conditions permit its use.[74, 81]

## MANUFACTURING METHODS

Although a great many different procedures have been suggested, particularly in the patent literature, only four major methods are of commercial importance. These are (1) roll welding, (2) casting, (3) intermelting and (4) arc and gas welding. In a few other commercial procedures several of these methods are combined as, for example, in the Colclad process developed in England.

### *Roll Welding*

In the roll welding method[12, 43, 46, 47, 49, 65, 70, 77] (also called the *heat and pressure method*) two heavy slabs of carbon or alloy steel of the desired mechanical or chemical properties are thoroughly cleaned on one of their flat surfaces. The stainless-steel "insert" plates are separately cleaned by an anodic pickling treatment usually in dilute hydrochloric acid. This may be followed by electrolytically plating a layer of nickel[43, 49, 70] or iron[20, 46, 53] on one side. The stainless-steel insert plates are then placed between the two steel slabs as shown in Fig. 1 and the resulting "sandwich" is sealed around the perimeter by a continuous weld which is generally made by submerged-arc welding.[28]

The primary function of the plated layer is to prevent the formation of chromium oxides on the surface to be bonded between the stainless steel and the backing carbon or alloy steel. The presence of such a chromium-oxide film, which is very refractory, would create a barrier to diffusion and would minimize or even prevent subsequent bonding of the stainless-steel insert plate to the backing steel.[12] In another procedure, used particularly in Germany, the chromium-oxide film is removed by hydrogen reduction—the hydrogen gas being passed through the composite slab during heating prior to rolling.[12] Bonding between the stainless-steel cladding plates themselves is prevented by means of an infusible parting compound which usually consists of a refractory oxide, as, for example, aluminum oxide[12, 40] mixed with a lacquer which is "painted" on the insert plates in the form of an aqueous paste.

Upon assembly the sandwich is heated in a soaking pit to a temperature of 2100 to 2350° F. (1150 to 1290° C.) which depends upon the type of cladding and the rolling procedure used in the mill. Rolling reduces the thickness of the composite material and bonds the cladding plate to the base steel—generally maintaining the stainless and backing steel in the same proportion from the assembled slab to the rolled plate. After rolling, the four edges of the slab are sheared or flame cut and the clad plates are then separated.

### *Casting*

In the casting method[12] the composite slab is produced by casting mild steel around an assembly of two stainless plates which are separated by the infusible parting compound and welded around the perimeter as illustrated in Fig. 2. Oxidation of the stainless-steel surface is usually not as severe as in the sandwich-type slabs prepared for roll welding in which nickel or iron plating is necessary. Nevertheless, for best bonding results, the stainless-steel inserts in the casting method also are often nickel plated by many producers. The composite cast assembly is then rolled as in the roll-welding method and separated into two stainless clad plates by shearing or flame cutting. Although many producers of stainless clad steels have investigated the casting process, the resulting clad plates are often not uniform along the bond. For this reason the majority of producers prefer the roll-welding method.[11, 64]

### *Intermelting*

In the intermelting method[11, 18, 22] which is illustrated in Fig. 3, a refractory wall is used to form the bottom and the three sides and a steel slab is used as the fourth side of an open-top mold. In the resulting jacketed space, proper proportions of the various ingredients (iron, chromium, nickel, etc.) making up the composition of the stainless steel are intermelted with the surface of the base steel ingot by a special electric-arc furnace to produce an integrally bonded cladding. In this process, a substantial amount of the base steel is intermelted to form part of the steel cladding. Because of the high temperatures involved [temperatures as high as 3500 to 4500° F. (1925 to 2480° C.) have been measured[78]] and the extremely rapid rates of diffusion at these temperatures the intermelted materials generally form a uniform solution[78] so that by proper control of the stainless alloying ingredients a fully austenitic cladding can be obtained with a sharp junction (bond) between the stainless cladding and the backing steel.[18, 78] The resulting clad slab is heated and rolled to the required thickness in the usual manner. Because of the relatively large amount of base steel that is melted off and mixed with the stainless-steel cladding, there are some limitations in both the types of backing steels and cladding alloys used in making composite clad steels by employing the intermelting method:[64] for example, when an essentially non-ferrous cladding metal such as a high-nickel alloy is to be clad to a mild steel.[78]

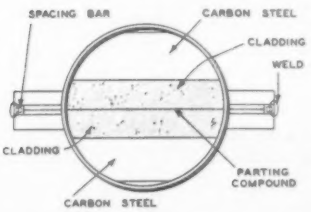



*Fig. 1 Sectional side view of clad stainless steel assembly prior to roll welding*[12]

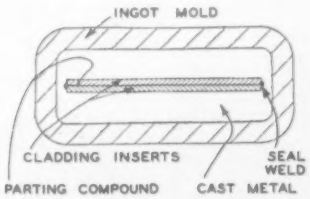



*Fig. 2 Sectional top view of clad stainless steel assembly made by casting method*[12]

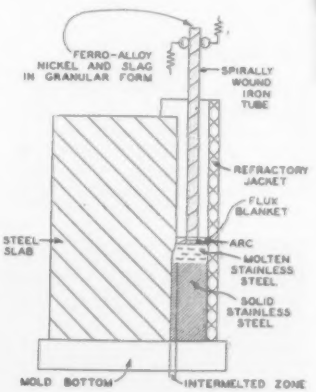



*Fig. 3 Side view sketch of cladding procedure by intermelting method*[12]

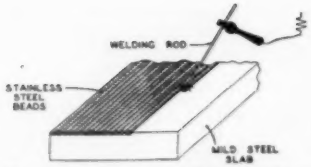



*Fig. 4 Sketch of cladding procedure by manual or automatic arc welding.*[12] *(A number of beads may be deposited similarly)*

### *Arc and Gas Welding*

In arc and gas welding, illustrated in Fig. 4, overlapping beads of weld metal of the desired stainless-steel composition may be deposited by shielded metal-arc welding, submerged-arc welding, atomic-hydrogen welding or oxyacetylene welding onto one face of the base steel slab. Automatic procedures are generally preferred over manual procedures. The resulting clad slab is then heated and rolled in the usual manner.

### *Colclad Process*

In the commercial Colclad process[13, 26, 43, 56] thin overlapping mild steel weld beads are deposited upon one surface of a stainless-steel insert plate measuring, for example, 4 ft. by 2 ft. 6 in. by 6 in. The welding procedure must be such that the penetration is held to a minimum to reduce as much as possible the effects of dilution. One or several thin mild-steel plates are then welded on top of the initially welded mild-steel layer which had been suitably descaled. This results in a slab similar to the one illustrated in Fig. 5. This slab is subsequently hot rolled to give a plate about $^1/_2$ to 1 in. thick. This specially prepared stainless-steel plate provides the cladding inserts used in the final composite slab which is assembled as shown in Fig. 6 and subsequently hot rolled to the desired clad plate thickness.

### *Carbon Pick-Up*

The ferritic chromium stainless steels and particularly the austenitic chromium-nickel stainless steels readily absorb carbon. If this leads to intergranular precipitation of chromium carbides at the surface of the finished clad plate, the clad plates may be unsuitable for service in those environments in which intergranular corrosion may occur.

Carbon diffusion may occur from the backing steel into the stainless steel,[16, 60] particularly if the latter is austenitic. This, however, is rarely detrimental to the corrosive properties on the surface of the plate since chromium carbides, if they precipitate, do so in the bond zone. This agrees with experiences of the majority of the clad stainless-steel producers in the United States who make stabilized (Types 321 and 347) as well as unstabilized (Types 304 and 316 and their extra-low-carbon modifications) clad stainless-steel plates and sheets. On the other hand, the European producers of clad stainless steels, on the basis of their experiences, seem to produce only clad stainless-steel plates using stabilized grades.[11, 21] More undesirable is the carbon pick-up from the atmospheres which may exist at the surface of the stainless-steel plate.[16, 60] Unless special precautions are taken, the immediate surface layers of stainless steels usually pick up a few hundredths of a per cent of carbon. This carbon pick-up may be minimized or prevented by the insertion of substances which inhibit gaseous carbon from reaching the surface or by flushing the surface with an inert gas.[16] There have also been some difficulties experienced in the production of composite steel plates with one of the extra-low-carbon grades as cladding material because of surface pick-up of a few hundredths per cent of carbon. Although some authorities now feel that carbon pick-up on the surface of these stainless clad steels is no longer a problem,[61] most producers of plates clad with the extra-low-carbon stainless steel materials do not presently guarantee a maximum carbon content to the same specification as the A.I.S.I. standard of 0.03% max. carbon.[61] Instead most producers will agree to procure 0.03% max. carbon stainless steel plates for insert plates, to electroplate one surface, and then to prepare commercially clad plates from the material by using the roll welding or casting processes.[68]

## NATURE OF BOND ZONE

The nature of the bond zone depends very much on the type of process used in making the composite plate. Whereas in some processes a considerable amount of dilution may occur because of intermelting (fusion or mixing) of part of the stainless steel with part of the mild steel, in other processes actual dilution may be negligible. Generally, when considerable dilution is expected to occur, sufficient alloying materials are added to the stainless steel to prevent any detrimental effects which may be the result of such dilution. In fact, in those continuously clad joints in which unexpected dilution may occur, it generally is not detrimental so long as brittle intermetallic phases do not form in the fusion zone and so long as the dilution does not reach the surface of the stainless steel. In the latter case, dilution may seriously reduce the corrosion resistance by reducing the alloying composition at the surface.

In roll welding and casting, dilution is generally negligible.

On the other hand, clad stainless steels produced by arc welding may exhibit a fusion zone in which considerable dilution (mixing) occurs in the weld metal—even though the junction between the diluted weld metal and the heat-affected zone may be sharply defined.

However, as long as a layer of undiluted stainless steel remains on the surface of the rolled plate, any dilution at the bond generally is not likely to give serious concern.

### *Carbon Diffusion*

Noticeable carbon migration may occur across the bond whenever any two ferrous alloys of different chemical compositions are intimately joined together and are exposed to temperatures at which the diffusion rates of carbon in steel are appreciable.* In stainless clad steels carbon tends to diffuse from the mild or low-alloy backing steel into the stainless steel.

Although carbon migration does not ordinarily become noticeable unless the composite steel is exposed to temperatures above 1050° F. (565° C.), the clad plates which have been produced by rolling will exhibit a narrow decarburized zone on the backing steel side of the bond zone and a carbon concentration on the stainless side. In austenitic stainless clad steel diffusion rates tend to be more rapid along

* For welded dissimilar-metal joints the effects of carbon diffusion have already been discussed in considerable detail in an earlier review.[5]

*Fig. 5 Stainless steel "insert" slab prior to assembly and roll welding*[13]

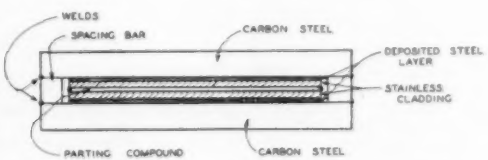



*Fig. 6 Sectional side view of Colclad stainless steel assembly prior to roll welding*[26]

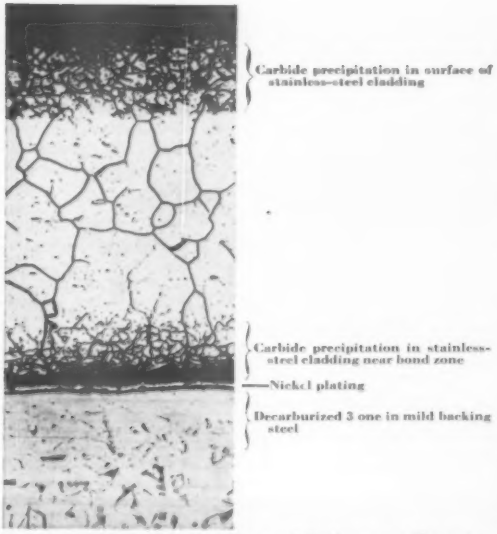

Carbide precipitation in surface of stainless-steel cladding
Carbide precipitation in stainless-steel cladding near bond zone
Nickel plating
Decarburized 3 one in mild backing steel

*Fig. 7 Intergranular carbide precipitation near the surface and the bond zone in Type 304 stainless clad steel after severe sensitizing at 1100° F. (595° C.). Magnification 100 ×. (Etchant: Oxalic acid)*

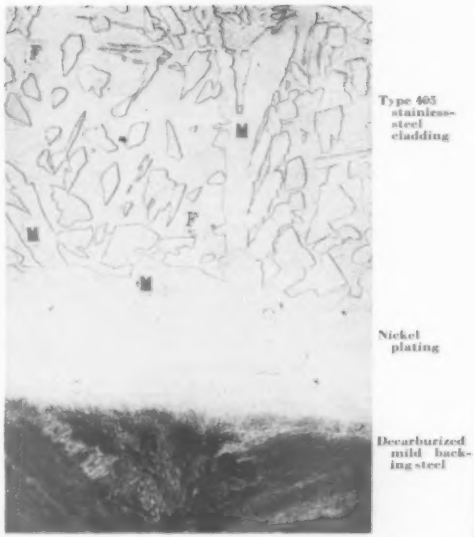



*Fig. 8 Type 405 stainless clad steel after quenching from 1800° F. (980° C.) showing (M) martensite and (F) ferrite in stainless steel. Magnification 200 ×*

the grain boundaries and this is frequently evidenced by intergranular carbide precipitation. An unusually severe case of intergranular carbide precipitation near the bond zone of a Type 304 stainless steel cladding, which is the result of carbon diffusion from the backing steel, is shown in Fig. 7. Such extreme cases, however, are rarely found in commercially clad stainless steels—unless they have been excessively exposed at high temperatures and for periods which permit these severe cases of carbon diffusion. In commercial practice Type 304 stainless clad steel would not be exposed to 1100° F. (595° C.), since only the stabilized Types 321 and 347 are recommended for service above 800° F. (425° C.).

In fully martensitic chromium stainless clad steels, the higher carbon content increases the hardening effect of the martensite at the bond zone. Chromium stainless steels which ordinarily are either ferritic-martensitic (Type 405 or 430, or low-carbon Type 410) or fully ferritic tend to have a narrow martensite layer along the bond zone of quenched or air-cooled alloys because of a higher carbon content, Fig. 8. Tempering below 1500° F. (815° C.) causes carbide precipitation within those grains which had initially been martensitic, Fig. 9.

Although the decarburized zone in the backing steel and the carbon-rich zones in the stainless steel tend to be mechanically weak zones, they are generally not detrimental in clad steel. This is due to the fact that these narrow zones of weakness, if they are present, lie parallel to the surfaces of the steel; and, thus, the over-all strength of the composite steel is not decreased sufficiently to cause concern. On the other hand, as was discussed earlier,[b, 9] in dissimilar-metal welds, which are transverse to the steel plate, carbon migration may be detrimental since the resulting zones of weakness pass through the cross section of the steel.

The presence of a narrow nickel-plated layer between the stainless-steel cladding and the backing steel considerably reduces carbon diffusion.[10] This is apparent from Fig. 10 which shows that when the nickel-plated layer is discontinuous, carbon migration from the backing steel to the stainless-steel cladding occurs through the "breaks" in the nickel-plated layer. These "breaks" in the nickel layer are rarely found in commercially produced stainless clad steels.

Although nickel considerably reduces

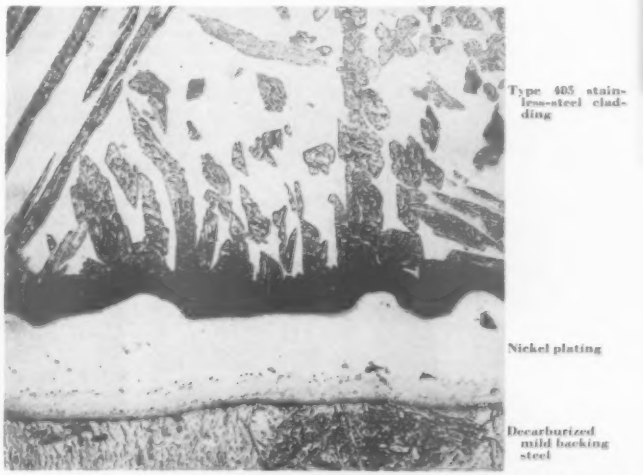



*Fig. 9 Type 405 stainless clad steel tempered 1 hr. at 1350° F. (730° C.) showing carbide precipitation on the stainless steel side of the bond zone. Magnification 200 ×*

carbon diffusion, exposures at sufficiently high temperatures for sufficiently long exposure periods allow diffusion of carbon through the nickel (see Figs. 7, 8 and 9). It has also been shown that with a nickel layer at the bond, applied as a powder, carbon diffusion from the mild-backing steel into the 18-8 (Cr-Ni) stainless-steel cladding during the roll-welding process was to a depth of 0.012 in.[73] When some ferrotitanium was added to the nickel powder the carbon diffusion into the stainless-steel cladding was reduced to a depth of 0.004 in. Carbon diffusion, however, became more severe and to a greater depth after subsequent annealing at 1830° F. (1000° C.) for periods up to 100 hr. The use of titanium alone as intermediate layer produced poor bonding of the cladding to the backing steel.[73]

Since carbon does not readily diffuse through copper even at elevated temperatures, it has been suggested[20] that an electroplated flash coating of copper between the stainless insert and the base steel might well prevent carbon diffusion. This however, seems undesirable because the copper itself tends to diffuse into the steel at temperatures above 1900° F. (1040° C.) and to produce a weak, hot-short alloy phase along the grain boundaries.[30] Since this hot-short alloy phase is highly undesirable,[6, 21] its consequences may be quite serious. Good results seem to be obtained when, instead of copper, a cupro-nickel alloy, which has a higher melting point than copper, is used between the stainless-steel cladding and the backing steel.[19] The cupro-nickel alloy containing about 60 to 80% copper is usually spot welded in the form of 0.020-in. thick sheets to the stainless-steel insert plates which are subsequently assembled into a sandwich (see Fig. 1). Heating temperatures prior to hot rolling should not exceed 2000° F. (1095° C.). This procedure has been particularly important

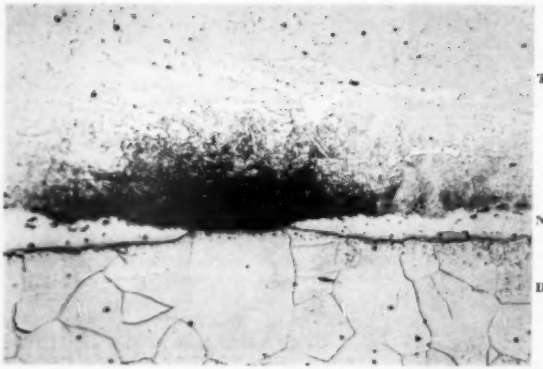



*Fig. 10 Carbide precipitation resulting from carbon diffusion through "breaks" in nickel-plated layer. Steel heated 1 hr. at 1650° F. (900° C.) furnace cooled to 1000° F. (540° C.) and air cooled. Magnification 200 ×. (Etchant: 2% Nital)*

*Fig. 11 Cracking in partly drawn Type 430 stainless clad steel pan caused by brittle high-carbon layer in stainless-steel cladding near bond line.[52] Reduced to one-third of actual size*

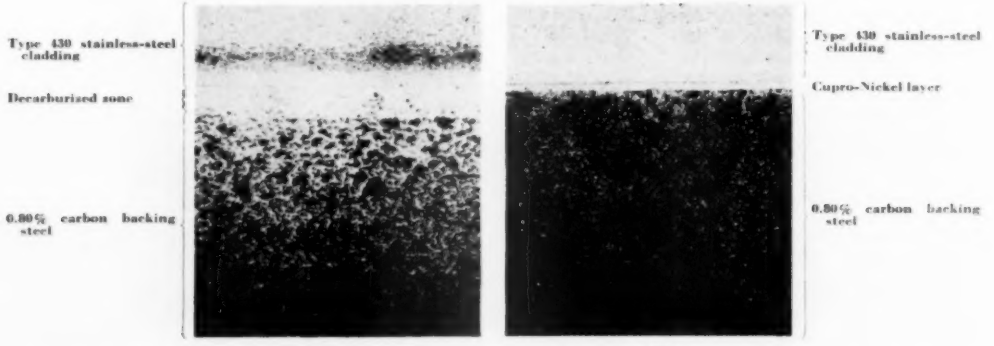



*Fig. 12 Bond areas in Type 430 stainless clad steels. (A) illustrates effect of carbon diffusion from 0.80 carbon parent steel into stainless-steel cladding and the resulting concentration of carbides above bond line. (B) illustrates effect of cupro-nickel layer in preventing carbide diffusion across bond.[52] Magnification 100 ×*

in the production of thin Type 430 stainless-steel clad strips (high-carbon backing steel used) hot-rolled from about 3 in. to 0.1 in. and subsequently severely cold formed. During batch annealing, a considerable amount of carbon diffusion from the relatively high-carbon backing steel into the stainless steel, which occurs when no cupro-nickel layer is present, tends to reduce considerably the cold-workability of the stainless-steel cladding.[52] This is evident from Fig. 11 which shows cracking in the stainless-steel cladding as result of a brittle high-carbon layer in the cladding near the bond.[52] Figure 12 shows photomicrographs of the bond area in two Type 430 stainless clad steels one of which contained an intermediate cupro-nickel alloy layer. Deep drawing of the latter strips did not result in the cracking shown in Fig. 11.[52]

When welds are made in certain types of stainless clad steels, an excessive carbon pick-up in the bond zone may sometimes be responsible for lack of fusion or for cracks in the triple junction of the weld metal, the cladding and the backing steel. The consequences of carbon migration may be particularly detrimental when the fully martensitic* and medium-chromium, essentially ferritic† stainless steels are welded with Type 430 stainless steel electrodes, especially where postheat treatments are not applied‡. The welding heat can cause austenite to form in carbon-enriched stainless steel side adjacent to the bond zone which, upon cooling, will transform into martensite. (Fig. 8). On bending, this hard interfacial layer has been observed to cause cracks which begin at the inner surface and penetrate through the cladding or weld to cause failure of the bend test specimen.

An example of lack of fusion between a Type 405 cladding and a 16% chromium stainless-steel weld metal is shown in Fig. 13.[63] The high-carbon area of the heat-affected zone of the Type 405 cladding shows a peculiar intergranular structural formation, Fig. 14, which suggests incipient melting and is generally not found in the heat-affected zone of (low-carbon) Type 405 weldments in which carbon pick-up did not occur.[52] The use of austenitic stainless-steel electrodes, which is the usual practice, generally prevents the lack of fusion, shown in Fig. 13. Moreover, under proper welding conditions lack of fusion and cracks may also be prevented when 16% chromium stainless-steel electrodes are used.

### *Alloy Diffusion*

Alloy diffusion is also likely to occur at elevated temperatures. Since nickel does not readily diffuse into iron, a nickel-iron martensite (25% nickel) does not form between the intermediate nickel-plated layer and either the base steel or the stainless steel.[58] Although some iron diffuses into the nickel, it is usually in such small quantities that it does not produce undesirable effects.

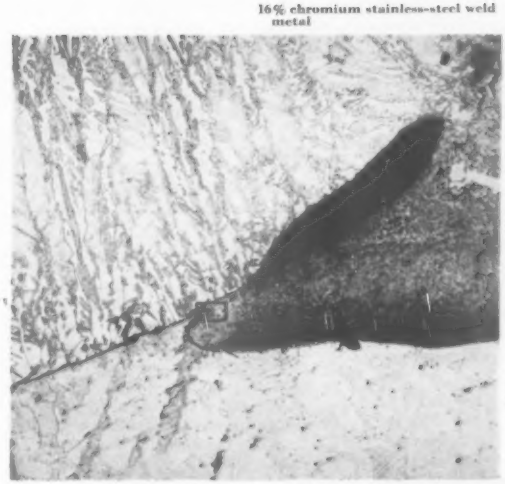



*Fig. 13 Triple junction of 16% chromium stainless-steel weld metal, Type 405 stainless-steel cladding and mild-steel backing which shows a void extending along the bond. Specimen was taken from bend test plate which was neither preheated nor stress-relieved.[63] Magnification 75 ×. (Etchant: 10% Hydrochloral-electrolytic)*

## PHYSICAL PROPERTIES

### *Expansion and Thermal Conductivity*

Expansion and thermal conductivity of the stainless clad steels are generally assumed to be proportional to the relative thicknesses of the backing steel and the stainless cladding.[59]

Since the chromium stainless steels have coefficients of expansion similar to the backing steel, they may be preferred on this account over the austenitic grades for application in applied liners where thermal cycling or shock may lead to deformation, and possibly, to failure of dissimilar-metal joints. In the integrally clad stainless steels thermal fatigue and shock are rarely a cause for failure—even when the cladding material is fully austenitic stainless steel.

The thermal conductivities of mild or low-alloy backing steels are considerably higher than those of stainless steels. The differences are particularly large between austenitic stainless steels and mild steels as is apparent from the following typical thermal conductivity values[75]

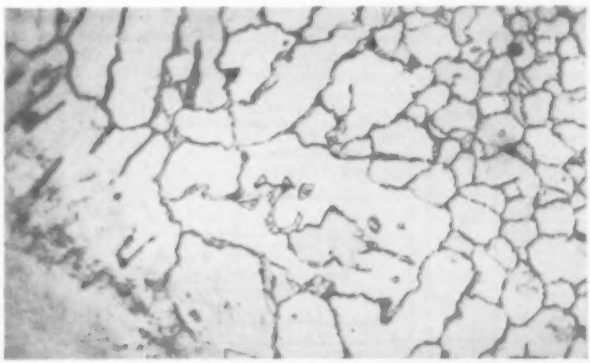


*Fig. 14 Detail of two-phase grain structure in heat-affected zone of of Type 405 stainless-steel cladding. Location of structure is indicated by rectangle in Fig. 13. This structure is confined to an area near the rectangle.[63] Magnification 1000 ×. (Etchant: 10% Hydrochloral-electrolytic)*

* Type 410.
† Types 405, 430.
‡ For example: Section 7 of the Interpretations of the ASME Boiler Code, Case 896, states that stress-relieving treatments may be omitted on Type 405 (ASME Grade O) and Type 410 with 0.08% max. carbon (ASME Grade A) when welded with austenitic electrodes.

| Temperature ° F. | Temperature ° C. | Thermal conductivity - cal./sq. cm./cm./°C./sec. Mild steels | Type 410 stainless steels | Type 304 stainless steels | Type 310 stainless steels |
|---|---|---|---|---|---|
| 212 | 100 | 0.138 | 0.059 | 0.039 | 0.030 |
| 392 | 200 | 0.127 | 0.062 | 0.042 | 0.033 |
| 572 | 300 | 0.118 | 0.064 | 0.045 | 0.036 |
| 752 | 400 | 0.109 | 0.066 | 0.048 | 0.039 |
| 932 | 500 | 0.098 | 0.069 | 0.051 | 0.042 |
| 1112 | 600 | 0.088 | 0.071 | 0.054 | 0.044 |
| 1292 | 700 | 0.079 | 0.073 | 0.057 | 0.047 |

Thus in applications where good heat conductivity is desirable the stainless clad steels have a definite advantage over solid stainless-steel grades.[77]

## MECHANICAL CONSIDERATIONS

### *ASTM Requirements**

ASTM Specifications† for the chromium[66] and chromium-nickel[67] continuously clad stainless steels require that the tensile properties of the clad (cladding along one side of test bar) plate be equal to or greater than the minimum requirements prescribed in the ASTM Specifications for the base steel plate. Two bend tests of the composite plate should also be made, one with the alloy cladding in tension and the other with the alloy cladding in compression.

On plates more than $^3/_{16}$-in. thick, the purchaser may also require shear tests (see Fig. 15) of the stainless cladding and the backing steel to show a minimum shear strength at the bond of 20,000 psi. (Ordinarily, stainless clad steels will exhibit a shear strength at the bond which varies between 40,000 and 60,000 psi.) As an alternative, the purchaser may require three bend tests with the stainless cladding in compression to determine the quality of the bond. At least two of the three tests shall show not more than 50% separation on both edges of the bent portion. Greater separation shall be cause for rejection.

On sheets and strips less than $^3/_{16}$-in. thick bend-test specimens must stand being bent cold with the clad side in tension through an angle of 180 degrees—without cracking on the outside of the bent portion. The bending operation shall be made around a pin the diameter of which is equal to the thickness of the material. The axis of the bend shall be transverse to the direction of rolling.

### *Tensile Tests*

The tensile strength of the composite stainless clad steels generally amounts to the proportionate sum of the tensile strength of the backing steel section and the stainless clad section, i.e.,

$$\frac{TS_c \times A_c + TS_b \times A_b}{A_t} = TS_t$$

where the subscripts $c$, $b$ and $t$ refer to the cladding, the backing steel and the "total" composite plate, respectively. $TS$ and $A$ stand for tensile strength and area, respectively.

In the determination of the adhesion of the cladding to the backing steel the tensile test is not as critical a test as the bend or torsion test because the two layers act in parallel.[60]

### *Bend Test*

Full bending represents an excellent test for the adhesion of the stainless cladding to the backing steel. Bend tests should be made with the cladding both on the inside and on the outside, that is with the clad metal under compression and tension, respectively. In addition to the compressive or tensile stresses, shear stresses occur which tend to reveal major defects in the adhesion of the cladding.[60] In welded joints the full bend test indicates also embrittlement in the weld deposit and/or in the heat-affected zone of the cladding (see Fig. 27).

Whereas the full (180 degree) bend test is primarily used to test the quality of the stainless-steel cladding, notched-bar slow-bend tests, such as the Lehigh test, are sometimes used to evaluate the notch-sensitivity of the backing steel and the temperature range in which the transition from ductile to brittle behavior occurs in the steel. In these tests the notch is usually cut through the stainless-steel cladding.

### *Impact Tests*

By varying the location of the notch, impact tests have occasionally been made on clad specimens to evaluate the toughness of the stainless-steel cladding, of the backing steel or of both. Although very few test results have been published it has been shown on low-carbon mild steels clad with a thin layer of austenitic stainless steel that, as expected, the metallurgical structure underneath the notch considerably influences the notch-sensitivity.[71] For example, Charpy V-notch impact tests showed that in stainless clad steels, which had received a stress-relieving heat treatment in the vicinity of 1300° F. (705° C.), the backing steel exhibited a relatively high-transition temperature at which the behavior of the steel changed from ductile to brittle behavior.[72] Consequently, it seems desirable that the backing steel should be well grain refined by a normalizing heat treatment which considerably lowers the transition temperatures.[73]

* Additional requirements are given in Case 896 of the *Interpretations* of the ASME Boiler Code.[61] Since the given information primarily pertains to welded joints it is discussed in a separate section on page 157-s.

† Also ASME Boiler Construction Code Paragraphs No. SA-263 and SA-264, respectively.

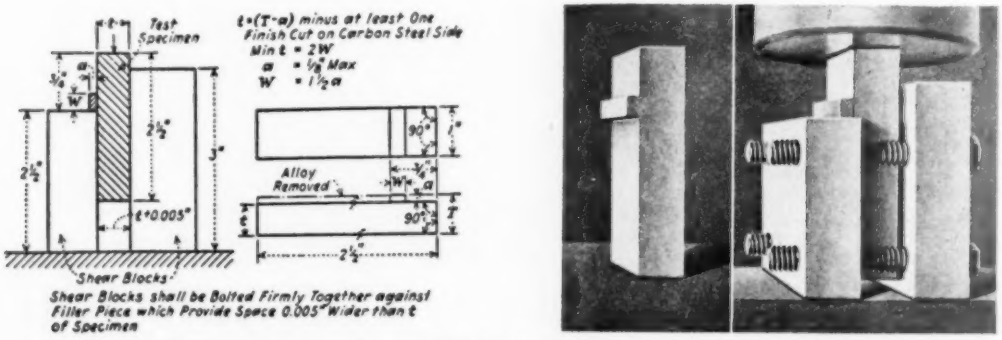

Test Specimen
t+(T-a) minus at least One Finish Cut on Carbon Steel Side
Min t = 2W
a = 1/8" Max
W = 1 1/2 a
Alloy Removed
t+0.005"
Shear Blocks
Shear Blocks shall be Bolted Firmly Together against Filler Piece which Provide Space 0.005" Wider than t of Specimen

*Fig. 15 ASTM test specimen and testing procedure for making shear tests of stainless clad steels*[25, 66, 67]

### *Fatigue Tests*

Results of repeated tension tests (60/40 ton pulsating Losenhausen type machine operating at a frequency of about 660 cycles per minute) are plotted in Fig. 16 for welded 18–8 (Cr-Ni) stainless clad steels.[57]

Richter[57] observed an apparent relationship between the alignment of the welded clad sections and the fatigue strength. He also reported that small pores, defective bonding, etc., did not exert as detrimental an influence on the fatigue strength as did misalignment of the sheets.[57]

Bend-fatigue tests also reveal the excellent adhesion of stainless clad steels. Results of Rädeker[58] on austenitic 18–8 (Cr-Ni) clad steels are listed in Table 1. (Specimen thickness and type of test not given.)

### *Quench-Fatigue Tests*

Quench-fatigue tests have occasionally been used to evaluate the adherence of the stainless-steel cladding to the backing steel.

Williams,[23] for example, reported that 20% clad Types 347 and 410 stainless-steel specimens showed no loss in their shear strength after 350 thermal-fatigue cycles which consisted of heating suitable clad specimens to 1000° F. (540° C.) and quenching to below 400° F. (205° C.).

Barr and Erskine[13] formed a 5-in. diameter cylinder from a 20% clad 18–8 (Cr-Ni) plate containing a single longitudinal butt weld. This cylinder was heated to 840° F. (450° C.) in an electric furnace and then dropped into a cold-water quenching tank. After several thousand heating and quenching cycles the cylinder was sectioned and examined. The bond between the stainless-steel cladding and the backing steel was found to be continuously effective throughout.[13]

### *Stresses in Clad Materials*

In the absence of plastic deformation, which would tend to relieve any internal stress differentials which exceed the proportional limit, the residual stresses in clad steels may be approximated from an equation by Schweizerhof.[16]

The tensile stress in the stainless steel is given by:

$$\sigma_1 = \frac{1}{(1-\mu)\left(\frac{1}{E_1} + \frac{t_1}{t_2}\frac{1}{E_2}\right)} \times \int_{T_0}^{T} (\alpha_2 - \alpha_1)\, dT$$

where $\sigma_1$ is the tension stress in the stainless cladding, $\mu$ is Poisson's ratio, $E_1$ and $E_2$ are the mean moduli of elasticity of the stainless cladding and the backing steel, respectively, between the temperatures $T_0$ and $T$, $t_1$ and $t_2$ are the respective thicknesses of the cladding and backing steel, and $\alpha_1$ and $\alpha_2$ are the coefficients of expansion of the stainless steel and the backing steel, respectively. The stress in the backing steel would then amount to:

$$\sigma_2 = -\frac{h_1}{h_2}\sigma_1$$

To calculate the residual stresses in a clad plate, which are caused by the differential in the coefficients of expansion between the stainless-steel cladding and the backing steel, a condition has to be assumed at which the duplex plate can be considered to be essentially stress-free.[20] This condition is believed by Keating[20] to be met at a temperature of 1110° F. (600° C.). Above this temperature little stress can be sustained because of its dissipation by plastic flow. Moreover, 1110° F. (600° C.) is about the highest temperature at which the backing steel can be considered to possess any appreciable elasticity.[20]

Cooling from 1110° F. (600° C.) will induce residual tensile stresses in the cladding.[20] At 570° F. (300° C.), in flat plates, these residual tensile stresses may amount to about 2000 to 4000 psi. because of the high plastic strain possible between 1110 and 570° F. (600 and 300° C.). At room temperature, the tensile stresses in the cladding of an ordinary plate will be of the order of 40,000 psi., or such lesser amount as will develop by plastic flow to reduce the residual stress to the actual proportional limit.[20] In most applications such a high tensile stress in the cladding will be of no practical significance because of the inherent ductility possessed by the austenitic stainless-steel material.

However, such a high internal tensile stress may be disastrous in environments which promote stress-corrosion cracking, and may cause failure in austenitic stainless-steel clad materials, even though the same environment may not cause cracking in a homogeneous austenitic plate exposed under the same conditions.[20]

When an austenitic stainless clad plate is formed by cold rolling into pipes or vessels with the stainless-steel cladding on the inside the stresses in the stainless-steel cladding would be compressive in nature[74] as long as they have not been relieved by plastic flow at elevated temperatures, as may be accomplished by heat treatments or by welding. For example, the heat dissipated by welding would remove part of the compressive stresses in the heat-affected zone of the stainless-steel clad-

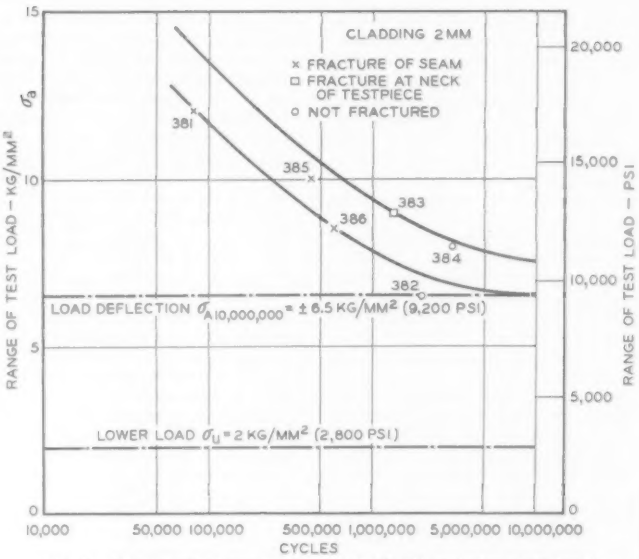



*Fig. 16 Results of fatigue tests on 18–8 (Cr-Ni) stainless clad steel*[57]

**Table 1—Results of Bend-Fatigue Tests on 18–8 (Cr-Ni) Stainless Clad Steels**[58]

| *Load, psi.* | *Number of cycles* | |
|---|---|---|
| ±33,400* | 4,200,000 | No failure |
| +22,800<br>−44,100 | 4,300,000 | No failure |
| +0<br>−66,800 | 1,000,000 | No failure |
| +21,300<br>−74,500 | 100,000 | Failure |
| ±43,400 | 900,000 | Failure |
| ±39,500 | 8,600,000 | No failure |
| ±42,200 | 2,100,000 | No failure |

* + = tension; − = compression.

ding by allowing plastic deformation and, upon cooling, the stainless-steel weld metal as well as the stress-relieved heat-affected zone in the stainless-steel cladding would exhibit residual tensile stresses instead of the compressive stresses which were initially present. Heat treatments above 1110° F. (600° C.) would introduce residual tensile stresses throughout the whole stainless-steel cladding inside the pipe.

Actually, sufficient information does not yet seem to be available on the effects of environments which cause stress-corrosion cracking upon the service behavior of stainless clad steels. In fact, there still exists considerable controversy as to amount and severity of residual stresses in clad plates.

Since new cases of stress-corrosion failures occur periodically, stainless clad steels should only be used when previous experience indicates immunity of the material to stress-corrosion cracking.[59]

## FABRICATION CONSIDERATIONS

Since mild steel is more readily cold formed than is austenitic stainless steel, austenitic stainless clad steels can be more severely drawn than solid stainless, which would require several intermediate annealing treatments.[16, 17, 25, 51, 77] Thus, cold-working procedures for composite steels, in which the cladding does not exceed by 20% the total plate thickness, are substantially the same as those used for the backing steel.

Martensitic and ferritic stainless steels containing up to 18% chromium (Types 410, 405 and 430) generally are readily formed when heat treated at temperatures at which the stainless cladding becomes fully ferritic.[34] The good cold-forming characteristics of these clad steel grades are generally related the fine grain size which the stainless-steel cladding has as result of partial austenite transformation at rolling temperatures which prevents severe grain growth at rolling temperatures as long as they do not exceed 2000°F.(1095° C.).[11] A clad ferritic stainless-steel grade, clad with a stabilized 17Cr–Ti or 17Cr–Cb+Ta stainless-steel alloy, is also manufactured in Germany because the stabilized cladding alloy is not embrittled as severely by welding as an unstabilized 17 Cr grade would be. However, since this stabilized grade does not become partially austenitic at hot-rolling temperatures it is more susceptible to grain growth so that in order to obtain a fine grain size, it is usually desirable to roll these fully ferritic grades at the lowest possible hot-rolling temperatures with large drafts.[11] This stabilized material generally exhibits poor cold-forming properties.[11]

In drawing operations, contamination of the stainless-steel surface, because of die pick-up and resulting die marks, is minimized by giving the drawing blank and stainless surface an intermediate finish and by applying a mar-proof coating to the surface of the stainless cladding.[16]

Shearing and punching are best done in such a way as to throw the burr on the backing-steel side.[16, 47, 48, 77] When this is impractical, the sheet or plate edges should be lightly ground or filed in order to remove the burr on the stainless-steel side.[16]

## HEAT TREATMENTS

Because of the differences in the coefficients of expansion of the stainless steel and the backing steel, single-clad plates tend to curl up badly on heating, particularly in the heavy per cent clad plates (20% or more). However, this is primarily a production problem for the manufacturer who delivers flat-clad plates, which have been flattened by suitable rolling procedures, to the user or fabricator. Since the differences in the coefficients of expansion between the backing steel and the stainless cladding are greater in the case of the austenitic chromium-nickel stainless steels than in the case of the chromium stainless steels, the austenitic clad grades show more difficulties.[17] These difficulties are not encountered with double-clad stainless steels or during the annealing of either small shapes with curved surfaces or of large circular vessels with dished heads made from single-clad steels.[17]

The selection of heat-treating temperatures has to be based on the characteristics of the backing steel as well as on those of the stainless-steel cladding. Thus, care has to be taken that a heat treatment is selected which produces beneficial effects in one material and yet does not produce detrimental effects in the other. Similarly, cooling rates have to be selected which will not be harmful to either of the two materials. For best results, the rates of heating should be the same as the rates of cooling, particularly in structures in which clad sections of different thicknesses are joined together.[47]

### *Annealing*

Ordinarily, stainless clad steel plates are annealed in open-fired, muffle-type furnaces. The annealing temperatures of stainless clad steels are generally lower than those used for solid stainless steels. Common annealing temperatures and procedures are listed in Table 2.[17, 25]

Austenitic stainless clad steels which are susceptible to intergranular carbide precipitation and are to be used in corrosive applications may have to be quenched by means of water-spraying the clad side after the annealing treatment at temperatures between 1825 and 1875° F. (1000 and 1020° C.). If warping has been caused by this severe quenching treatment the plates may have to be straightened mechanically as in roll straightening. However, air cooling is generally preferred for austenitic clad steels since quenching from above 1800° F. (980° C.) may produce some martensite in the carbon steel.

**Table 2—Annealing Temperatures and Procedures for Stainless Clad Steels**

| *Type* | *Temperature* ° F. | *Temperature* ° C. | *Time* — *Sheets and plates to 1/2 in.* | *Time* — *Plates 1/2 in. or over* |
|---|---|---|---|---|
| 302 | 1850–2000 | 1010–1095 | 1/2 hr. minimum, air cool | 1 hr. per in. of thickness, air cool or spray quench of clad side |
| 304 | 1825–1900 | 1000–1040 | 1/2 hr. minimum, air cool | 1 hr. per in. of thickness, air cool or spray quench of clad side |
| 308 | 1825–1900 | 1000–1040 | 1/2 hr. minimum, air cool | 1 hr. per in. of thickness, air cool or spray quench of clad side |
| 310 | 2000–2100 | 1095–1150 | 1/2 hr. minimum, air cool | 1 hr. per in. of thickness, air cool or spray quench of clad side |
| 316 | 1900–2000 | 1040–1095 | 1/2 hr. minimum, air cool | 1 hr. per in. of thickness, air cool or spray quench of clad side |
| 321 | 1800–1900 | 980–1040 | 1/2 hr. minimum, air cool | 1 hr. per in. of thickness, air cool |
| 347 | 1800–1900 | 980–1040 | 1/2 hr. minimum, air cool | 1 hr. per in. of thickness, air cool |
| 405 | 1400–1500 | 760–815 | 1/2 hr. minimum, air cool | 1 hr. per in. of thickness, air cool |
| 410 | 1450–1550 | 790–845 | 1/2 hr. minimum, furnace cool at 50°F. (28°C.) per hr. to 1100° F. (595° C.), then air cool | 1 hr. per in. of thickness furnace cool at 50° F. (28° C.) per hr. to 1100° F. (595° C.), then air cool |
| 430 | 1450–1550 | 790–845 | 1/2 hr. minimum, furnace cool at 50° F. (28° C.) per hr. to 1100° F. (595° C.), then air cool | 1 hr. per in. of thickness, furnace cool at 50° F. (28° C.) per hr. to 1100° F. (595° C.), then air cool |
| 446 | 1550–1600 | 845–870 | 1/2 hr. minimum, air cool | 1 hr. per in. of thickness, air cool |

Fabricated shapes such as vessel heads are sometimes required to be annealed and quenched. Martensite formation in the base steel is generally prevented by the selection of a relatively low-carbon A-285 backing steel. In addition, some manufacturers reduce the severity of the quench by applying the water-spray or steam-quenching medium to the stainless clad side of the composite plate.[64]

In any heat-treating operation it is desirable to minimize scale formation. This is particularly important in heat treatments of single-clad stainless steel sheets of light gage. The heavy scale which forms on the backing steel at annealing temperatures is often transferred to the stainless surface and may interfere with pickling and forming operations.[24] This scale formation may be minimized by the use of special furnace atmospheres or a radiant-tube, continuous-roller hearth furnace.[24]

## WELDING

The primary requirement of stainless clad steels generally is that they exhibit the same corrosion resistance as would corresponding solid stainless steels. Consequently, the welded joint must also exhibit, on the clad side, corrosive properties which are at least equal to those of the stainless steel used for the cladding. Moreover, the whole weld joint must provide sufficient strength and ductility to allow the structure to meet the service requirements for which it is designed.

Generally, stainless clad steels and applied liners are readily weldable. Certain factors however should be considered. These are: (1) welding procedure and process, (2) welding position, (3) positioning and fit-up, (4) groove preparation, (5) plate thickness, (6) dilution and (7) selection of stainless electrodes.

### *Welding Procedure and Processes*

The welding procedure and process used depends upon the type of joint and whether the weld can be made in any position or only in a particular position. For example, clad pipes of small diameter with the cladding on the inside can be welded only from the outside.

Whereas in thin sections below 1/4 in. in thickness the whole joint is generally made with austenitic stainless electrodes, in heavier sections both mild-steel and stainless-steel electrodes are ordinarily used, the mild-steel side generally being welded first. Welding of the stainless clad side first would usually cause the subsequent mild-steel deposits to be hard and brittle because the mild steel, by dissolving some of the earlier deposited stainless steel, will become alloyed and hardenable. (In metal-arc welding the mixing might amount to about 15 to 30%.)[8] Since highly alloyed stainless steel can tolerate more dilution than mild steel, the mild-steel side is welded first with mild steel electrodes. The subsequent welding of the stainless clad side with suitable stainless-steel electrodes also serves to stress relieve or anneal the mild-steel side.

A slow rate of electrode travel is generally desirable when depositing the initial 25–20 or 25–12 (Cr-Ni) stainless-steel root bead into the prepared mild-steel groove. Similar considerations hold true when depositing 18–8, 25–12 or 25–20 (Cr-Ni) weld metal upon stainless steel. The relatively slow rate produces a root bead which does not have as high a crown as would be produced with a more rapid rate of electrode travel. A fast rate of electrode travel generally will produce a high crown and will result in notches in both sides of the weld bead in a back-chipped or ground groove.[64] It is also difficult to remove the slag from such beads. A slow rate of travel, to produce a slightly convex or almost flat bead, is believed to be most desirable.[64]

Shielded metal-arc welding is generally used for the welding of stainless clad steels thicker than 18 gage (0.05 in.).[12, 48]

Submerged-arc welding is frequently used in welding the steel side of stainless clad steel.[64] However, prior to the submerged-arc welding it is necessary to deposit by manual metal-arc welding two block beads to prevent burn-through with the submerged-arc weld.[64] Because dilutions of the weld metal may be as high as 50 and 60%, this process is seldom used on the clad side of the plate which is more suitably completed by shielded metal-arc welding. Some development is now being done in the production of a special core wire to overcome the severe dilution of the submerged-arc welding process so that it may be possible to use this process in welding the clad side of these materials.[64]

Oxyacetylene welding is seldom used for clad stainless steels.

Atomic-hydrogen welding is primarily used on thin sections where stainless weld metal is deposited through the whole joint.[12]

Inert-gas metal-arc welding with a non-consumable tungsten or carbon electrode and with suitable filler rods under argon or helium gas has been successfully used—particularly when welding light-gage stainless clad steels.[12]

The inert-gas shielded metal-arc welding process, in which consumable stainless-steel electrodes are used, has been found to be readily applicable to the welding of stainless clad steels—particularly when the whole weld has to be made from the backing-steel side because the dimensions of the weldment prevent welding from the stainless-clad side. Stainless clad steel pipes, with the cladding on the inside, represent a typical example where welding has to be made from the outside. Under these conditions a special joint design and welding procedure must be used. A square-butt joint with a 1/32-in. root gap seems most suitable since the high-current densities obtained in this process produce a weld of considerable penetration.[69] Results of welding experiments by Watson and Rothermel[69] are given in Table 3. Because of the deep penetration and dilution of the weld metal it is important to use 25–20 (Cr-Ni) electrodes. Typical cross sections of welds made in one pass from the backing-steel side are shown in Fig. 17.

Resistance-butt welding has had no application in the welding of stainless clad steels.[12]

### *Effects of Welding Position*

In flat-position welding, AWS EXX20 or EXX30 electrodes should be used for the backing steel. To minimize penetration the root bead should be welded with proper current and a rather high rate of travel. In vertical or overhead welding, EXX10, EXX11, EXX15 or EXX16 electrodes should be used.[12, 24, 25, 64]

### *Positioning and Fit-up*

Good positioning and fit-up are important in welding the stainless clad steels.

In cylindrical pressure vessels, where heads are to be attached, it is important that the plates be laid out to match the internal diameter of the heads. Spun heads thicken on the straight flange section. Since the thickening is not predictable, it is necessary to check the individual heads and match the shell plates to them.[24] If the fit-up of the stainless clad sections is poor, EXX12, EXX13, EXX15 or EXX16 electrodes are recommended[12, 24, 25, 26, 64, 72] for welding the backing steel in all positions in order to minimize penetration and the danger of alloy pick-up from the cladding material or, in the case of the EXX15 and EXX16 electrodes, tolerate more alloy pick up by the weld metal.[64]

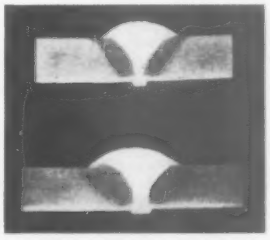



*Fig. 17 Cross sections of welds made by inert-gas shielded metal-arc welding in one pass from the backing-steel side. (A) shows Type 304 10% stainless clad steel, 3/8 in. thick, welded with 25–20 (Cr-Ni) wire. (B) shows Type 410 10% stainless clad steel, 3/8 in. thick, welded with 25–20 (Cr-Ni) wire*[69]

### *Design of Weld Joint*

Butt welds are generally preferred since they produce uniform penetration. Although some authors feel that fillet welds should be avoided whenever possible[14] in many types of construction such welds are mandatory. They can usually be successfully made without taking any particular precautions.[64] Welds made in corners are difficult to clean and grind. Undercutting along the edge of a fillet weld is not at all common, but, nevertheless, it is possible and, therefore, flanged and butt-welded joints are preferred to corner welds.

### *Groove Preparation*

After the backing-steel side has been welded, chipping or grinding of the clad side down to clean, sound weld metal is highly important in order to remove residual slag and any unfused area that, in the completed weld, would act as a stress raiser.[24, 72] A $^3/_{16}$- or $^1/_4$-in. round-nose chisel is preferred for chipping clad plates up to a thickness of about $^3/_4$ in. On plates over $^3/_4$ in. thick a $^5/_8$- to $^1/_2$-in. round-nose chisel should be used.[24, 72] Chipping is usually preferred over grinding since the chip will part as long as any unfused section remains, whereas in grinding the unfused area may be "smeared-over" with metal and thus become hidden.[24, 72]

A high-speed cut-off wheel should be used when the groove is prepared by grinding.[24, 72] Nevertheless, prior to the grinding operation a light groove should be chipped so as to provide a guide for the grinding wheel and thus to minimize the tendency of the high-speed grinder to throw the wheel.[24, 72] On clad plates up to $^1/_2$ in. thick a $^1/_2$-in. thick, 6-in. diameter wheel is ordinarily used for the initial cut. After the groove is cut to the required depth, a $^1/_4$-in. thick, 6-in. diameter wheel is often used in order to open up the top section of the groove and to provide adequate space in which to manipulate the welding electrode.[24, 72] On heavy cladding a $^1/_4$-in. thick wheel should be used for the first cut and followed by a $^3/_8$-in. or $^1/_2$-in. thick wheel to provide adequate groove width.[24, 72]

Excessive groove depths may be repaired either by depositing a steel bead from the clad side, taking care, however, that alloy pick-up from the stainless-steel cladding is prevented, or by increasing the groove width proportionally to allow sufficient electrode manipulation.[24]

Satisfactory groove preparation may also be accomplished by means of the recently commercially developed carbon-arc method using the *Arcair* Torch* which, for economic reasons, is likely to be used extensively instead of chipping and grinding.

On the clad side the following groove widths are ordinarily recommended: [24, 72]

| *Plate thickness, in.* | *10% clad, in.* |
|---|---|
| $^3/_{16}$–$^1/_2$ | $^1/_4$ |
| $^1/_2$–1 | $^3/_8$ |
| 1 and up | $^1/_2$ |

| *Plate thickness, int* | *20% clad, in.* |
|---|---|
| $^3/_{16}$–$^1/_2$ | $^5/_{16}$ |
| $^1/_2$–1 | $^1/_2$ |
| 1 and up | $^5/_8$ |

### *Sheets Up to 16 Gage (0.0625 In.)*

Thin sheets up to about 0.0625 in. thick are welded from the stainless side in one pass. Joint preparation, other than proper shearing, is not necessary for butt welds.[12] However, whenever possible, the joint should have a small root opening. 25–20 or 25–12 (Cr-Ni) electrodes are most commonly used for joining these thin gages.

### *Sheets Between Gages 14 and 11 (0.078 and 0.125 in.)*

Stainless clad steel sheets, from 14 to 11 gages, may be welded in two passes. The first pass is made from the clad side and the second from the backing steel side.[12] 25–12 or 25–20 (Cr-Ni) electrodes generally are used for both passes.

### *Plates $^1/_8$ to $^1/_4$ In. Thick*

Thin plates $^1/_8$ to $^1/_4$ in. in thickness are generally welded on both sides with stainless-steel electrodes.[9] The additional cost of using stainless-steel electrodes is largely offset by a saving of time in back-chipping or grinding of the joint and cleaning of the clad surface.

**Table 3—Welding Conditions and Bend-Test Results of Welds Made on Stainless Clad Steels with the Inert-Gas-Shielded Metal-Arc Welding Process[69]**

| *Type clad* | *Plate thickness, in.* | *Cladding, %* | *No. of weld passes* | *Side from which weld was deposited* | *Type wire* | *Wire diameter, in.* | *Current, amp.* | *Voltage* | *Travel speed, in. per minute* | *Gas* | *Gas flow, cu. ft. per hour* | *Free Bend, Elongation, % Steel in tension* | *Clad in tension* | *Side bend* | *Postweld treatment* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 304 | $^3/_8$ | 10 | 1 | Steel | 25–20 (Cr-Ni) | $^5/_{64}$ | 500 | 29–30 | 18 | Argon | 90 | 38.5, 40.0 | Bent satisfactorily | Bent satisfactorily | None |
| 304 | $^3/_8$ | 10 | 1 | Steel | 19–9 (Cr-Ni) | $^5/_{64}$ | 500 | 32 | 14 | Argon | 90 | 4.0, 4.0 | Bent satisfactorily | Did not bend | None |
| 304 | $^3/_8$ | 10 | 1 | Steel | 25–20 (Cr-Ni) | $^5/_{64}$ | 500 | 30 | 14 | 60 A<br>40 He | 90 | 20.4, 28.0 | Bent satisfactorily | Bent satisfactorily | None |
| 304 | $^3/_8$ | 10 | 1 | Steel | 25–20 (Cr-Ni) | $^5/_{64}$ | 500 | 30 | 14 | 75 A<br>25 He | 90 | 20.7, 21.6 | Bent satisfactorily | Bent satisfactorily | None |
| 304 | $^3/_8$ | 10 | 1 | Steel | 25–20 (Cr-Ni) | $^5/_{64}$ | 500 | 30 | 14 | 90 A<br>10 He | 90 | 36.7, 37.5 | Bent satisfactorily | Bent satisfactorily | None |
| 304 | $^3/_8$ | 20 | 1 | Steel | 25–20 (Cr-Ni) | $^5/_{64}$ | 500 | 31 | 14 | Argon | 90 | 42.3, 46.1 | Bent satisfactorily | Bent satisfactorily | None |
| 347 | $^3/_8$ | 20 | 2 | Steel clad | 25–20 (Cr-Ni) | $^3/_{64}$ | 490 | 30–31 | 14 | Argon | 90 | 48.2, 50.0 | ... | Bent satisfactorily | None |
| 410 | $^3/_8$ | 10 | 1 | Steel | 19–9–Cb (Cr-Ni-Cb) | $^1/_{16}$ | 370 | 29–30 | 38 | Argon | 90 | 55.5, 57.1 | Bent satisfactorily | Bent satisfactorily | S.R. 1150–1175° F.–1 hr. F. C. |
| 410 | $^3/_8$ | 10 | 1 | Steel | 25–20 (Cr-Ni) | $^5/_{64}$ | 500 | 29–30 | 18 | Argon | 90 | 31.2, 33.4 | Bent satisfactorily | Bent satisfactorily | None |
| 410 | $^3/_8$ | 10 | 1 | Steel | 25–20 (Cr-Ni) | $^5/_{64}$ | 500 | 29 | 15 | Argon | 90 | 31.4, 35.0 | Did not bend | Bent satisfactorily | None |

* This process will be discussed in a subsequent review.[70]

An 80-degree V-joint is usually made on the mild-steel side.[64] The mild-steel side should be welded first—unless the welding position requires that the stainless-steel side be welded first in order to provide down-hand back-chipping or grinding.[5, 27] Experiences also show that depositing a bead on the backing-steel side after the stainless-steel weld has been completed facilitates the cleaning of the slag from the stainless-steel weld beads.[5]

In arc welding, 25–20 or 25–12 (Cr-Ni) electrodes are generally used in order to minimize dilution so that the deposited stainless weld metal is still essentially austenitic.[5] Although 18–8–Cb (Cr-Ni-Cb) weld metal has given satisfactory service in milk tanks,[37] the 25–20 or 25–12 (Cr-Ni) electrodes are considered to be more suitable.

In welding sheets and thin plates, it is generally advisable to use copper chill bars[19] particularly when making the whole weld from one side alone with austenitic stainless-steel electrodes. This will cool the weld metal and adjacent steel quickly and, thus, minimize cracking failures.

### *Plates 1/4 to 1/2 In. Thick*

The welded joints of plates 1/4 to 1/2 in-in thickness should be prepared by planing or chipping as shown in Fig. 18.[47] In order to prevent dilution or melting of the stainless face material, it is important that the bevel remains within the backing steel, with a steel lip or root-face of a minimum of 1/16 in. between the bevel and the stainless cladding.

Plates 1/4 to 1/2 in. thick are most commonly welded by metal-arc welding. The following welding procedure is generally recommended[16, 47] (Fig. 19): (1) Tack plates from base steel side with steel welding electrodes, (2) complete weld on base steel side with steel electrodes, (3) chip out or grind out the clad side of joint to remove any unfused area completely. The chipped groove should only be deep enough to reach sound metal and must be wide enough to provide a good welding condition, (4) deposit on chipped groove the necessary number of beads or layers, using an electrode suitable for the cladding.

The first steel bead in the bottom of the groove on the steel side should be deposited relatively "hot," i.e., on the high side of the recommended current range.[64] Moreover, high rates of electrode travel are desirable. An electrode of small diameter is also preferable, as this, combined with high welding speed minimizes penetration and the consequent dilution of the stainless-cladding material. If the first steel bead penetrates into the stainless cladding and becomes alloyed, the initial deposit may become extremely hard and brittle. Cracks may also develop and the deposit will be difficult to chip out from the stainless clad side. The selection of the correct root-face, current, diameter and type of electrode, and welding speed avoids this difficulty.[47] Figure 20 illustrates the difficulties which may arise when a proper steel lip is not provided. Such a lip would have prevented melting of part of the stainless-steel cladding and the consequent alloy pick-up by the mild-steel root deposit which caused the cracking. The fact that some steel-electrode types are more susceptible to such cracking than other electrode types is apparent from Fig. 20 where the root bead made with an E6020 electrode had cracked, whereas the E6015 root bead had withstood the effects of the alloy pick-up.[64] A proper steel lip would have prevented cracking of the E6020 root deposit.

Clad plates over 1/4 in. thick generally do not require chill bars. This is because mild steel exhibits a greater heat conductivity than does stainless steel. Thus, the welding heat is usually conducted away sufficiently rapidly.[19]

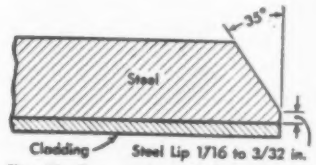



*Fig. 18 Preparation of edges for clad steel welds 1/4 to 1/2 in. thick*[47]

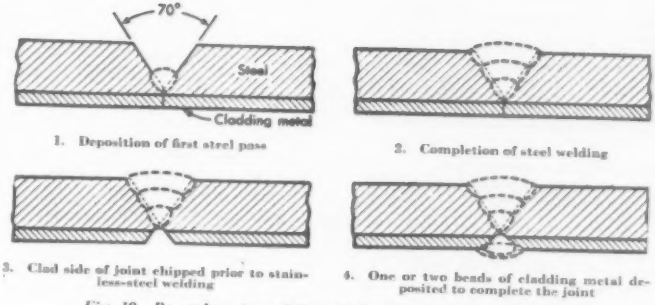

70°
Steel
Cladding metal
1. Deposition of first steel pass
2. Completion of steel welding
3. Clad side of joint chipped prior to stainless-steel welding
4. One or two beads of cladding metal deposited to complete the joint

*Fig. 19 Procedure in welding clad steel 1/4 to 1/2 in. thick*[47]

### *Plates Over 1/2 In. Thick*

The welding of heavy stainless clad plates requires a number of further considerations. Of primary importance are the high restraint and rapid cooling rates of the weld metal which, in addition to the differences in the coefficients of expansion, may produce cracks and result in low ductility in the weld metal and in the heat-affected zones.

Ordinarily, most manufacturers of stainless clad steels recommend a joint preparation for plates over 1/2 in. as illustrated in Figs. 18 or 21.[12, 24, 27, 47, 72, 74] The latter is generally preferred for the heavier plates (over 3/4 in.). Again a steel lip or root face of at least 1/16 in. should be allowed to remain between the bevel and the stainless cladding.

Although these joints are satisfactory for the welding of plates which are well positioned and clamped, serious distortion may occur in field welding. The difficulties seem to be particularly severe for the horizontal welding position.[5]

Since in the conventional joint (Figs.

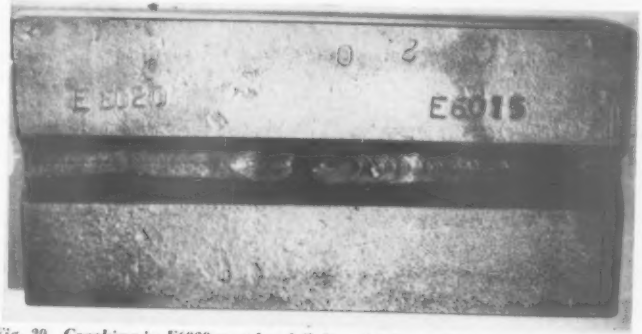



*Fig. 20 Cracking in E6020 root bead (left weld deposit) caused by alloy pick-up due to absence of proper steel lip. The E6015 root bead (right weld deposit) withstood detrimental effects of alloy pick-up.*[64] *Reduced to one-half of actual size*

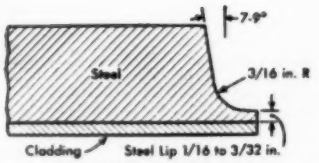



*Fig. 21 Joint preparation for plates over 1/2 and, particularly, over 3/4 in. thick*[42]

18 and 21) the major portion of the weld metal is deposited from the mild-steel side, serious distortion and buckling may occur during the cooling of plates which cannot be completely clamped. An example of this is shown in Fig. 22 for a free (not clamped) V-joint before and after welding. The test plate warped toward the backing-steel side. In addition, such joints require that stainless weld metal is deposited to a considerable depth—generally over twice the thickness of the cladding. This seems undesirable particularly if the joint is used in structures which are exposed at elevated temperatures.[8] Distortion in the joint, as shown in Fig. 22, is also less when a slight gap of about 1/16 in. is used than when the plates are tightly butted.[54]

The distortion problem may be overcome by the double V-joint shown in Fig. 23.[8] By welding the backing steel from both sides, distortion is minimized. Moreover, the thickness of the stainless weld is kept to a minimum.

Because of the greater width of the face of the stainless-steel weld, more stainless weld metal is required in the double V-joint (Fig. 23 (*A*)) than in the single V- or U-joints (Figs. 18 and 21). Moreover, practical welding experiences indicate that it is more difficult to produce a double V-joint which can be qualified in accordance with the code requirements.[8] The reason is that in double V-joints the bend elongation with the stainless clad side in tension is somewhat lower than if single V- or U-joints had been used.[8] When the full-bend ductilities of test specimens fall below 20%, the welds may not qualify according to many code requirements. Nevertheless, according to Arnold[3] many producers seem to prefer the double V-joint when welding clad plates over 3/4 in. in thickness.

25–20 or 25–12 (Cr-Ni) electrodes are generally used to weld the heavy gages. However, because restraint increases with the thickness of the plate, these stainless-steel electrodes which produce satisfactory root welds in 1/8 or 1/4-in. plates may not produce comparable results in 3/8-in. and thicker plates. Thus crack sensitivity may be reduced by use of 25–20 (Cr-Ni) electrodes which are on the high end of the permissible carbon range (about 0.15 to 0.20% carbon).[63] Good results have also been obtained by depositing an initial layer from a standard 25–20 (Cr-Ni) electrode and following this by a second layer from a 29–9 (Cr-Ni) electrode. This latter procedure appears to be fairly satisfactory in the as-welded condition.[63]

### *Dilution*

The fact that some mixing occurs between the weld metal and the parent steel has been already pointed out.[8] This may be detrimental if the resulting mixed or diluted carbon-steel weld metal exhibits a structure which is crack sensitive. Moreover, when the composition of the surface of the stainless-steel weld metal is changed by dilution, the corrosion resistance may be reduced.

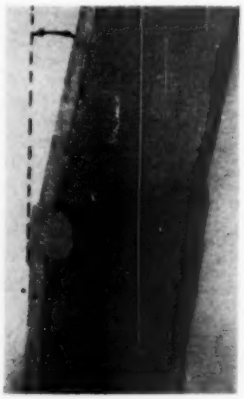
As far as crack sensitivity is concerned, the austenitic stainless-steel weld metal can tolerate considerable dilution from mild steel—particularly when the more highly alloyed 25–12 or 25–20 (Cr-Ni) electrodes are used. On the other hand mild-steel weld metal can tolerate very little dilution from austenitic-stainless steel materials. Thus, when welding clad stainless steels from the backing-steel side with mild-steel electrodes, it is important that the mild-steel weld bead is not diluted by the stainless-steel cladding.

An earlier review[6] discussed how dilution may be analyzed. Since in clad steels as many as three or four different materials may be involved, the analysis is somewhat more complex.

Figure 24 gives an illustration for a Type 410 stainless clad steel.[9] When the initial weld bead is deposited, parts of the 410 stainless cladding and the mild steel are simultaneously melted. This is represented by point *x* on the diagram. If a normal 25–20 (Cr-Ni) electrode is used, the resulting deposit will be fully austenitic (assuming dilution ranging between 20 and 35% on the line *x*). According to Schaeffler,[9] this deposit or any fully austenitic deposit from commercial electrodes will be subject to fissuring if considerable restraint exists in the weldment. However, if a relatively high-carbon (0.15 to 0.20%) 25–20 (Cr-Ni) electrode is used, the inherent character of the austenite is changed and the deposit is more resistant to fissuring.

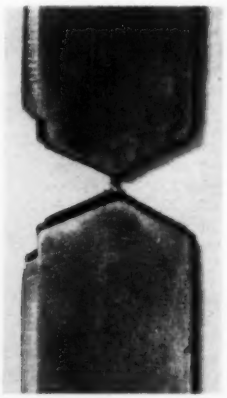
Figure 25 illustrates what occurs when an electrode capable of producing a partially ferritic deposit is used.[9] In this example, a 29–9 (Cr-Ni) electrode is selected for the first layer and again the first (root) bead is directed at point *x*. With 20 to 35% dilution, the first bead is found to contain about 25% ferrite. The second bead welded is a combination of Bead 1 and mild steel. If equal amounts of mild steel and 29–9 (Cr-Ni)

(*A*)



(*B*)

*Fig. 22 Conventional joint on 3/8-in. stainless clad plate showing warpage as result of initial welding from mild steel side*[8]



(*A*)

(*B*)

*Fig. 23 Recommended joint to prevent excessive warpage in 3/8-in. stainless clad plate*[8]

electrode metal are melted, the dilution direction line will be drawn from the 29–9 (Cr-Ni) electrode (point *R*) to point *y*. Bead 2 would then be expected to contain about 20% ferrite. The remaining beads of Layer 1 can be followed in a like manner. All weld beads will contain an adequate amount of ferrite for the prevention of fissuring; in fact, as Schaeffler[2] pointed out, with this large amount of ferrite the weld may not be sufficiently ductile and, thus, separation along the bond may occur during bending, before the required elongation is realized. in this case, Schaeffler[2] believes that 27–13 (Cr-Ni) [point *S*] and 25–12-Cb (Cr-Ni-Cb) [point *T*], which produce weld deposits with only about 10 or 5% ferrite, respectively, would produce better deposits than the 29–9 (Cr-Ni) electrode would.

This type of analysis is becoming quite helpful in the selection of suitable welding electrodes.[42]

Since excessive dilution in the stainless clad weld may be undesirable from the corrosive point of view, it is often advisable to minimize dilution by depositing multiple passes. However, when only one bead can be deposited, 25–20 or 25–12 (Cr-Ni) electrodes usually are recommended.[14, 18]

### *Selection of Stainless Electrodes*

After the backing-steel side has been welded, the clad side of the weld joint should be welded with the electrodes recommended in Table 4.[25, 39] Stabilized austenitic electrodes should be used if the weldment is to be exposed to temperatures at which carbides precipitate, that is at temperatures above 800° F. (425° C.). Unstabilized low-carbon stainless-steel electrodes have also given satisfactory service in welded stainless clad steel equipment used in the chemical industry as long as the weldment has not been exposed at temperatures above 800° F. (425° C.)[11] where carbide precipitation, aggravated by carbon diffusion from the backing steel, may make the weldment susceptible to intergranular corrosion.

In Table 5 are listed the electrode diameters and current ranges which are recommended for stainless clad steels of different thicknesses.[12, 39]

### *Austenitic Stainless Clad Steels*

Because of their relatively high-carbon content, Types 301 and 302 are rarely used in corrosive applications. Instead these two grades are used primarily in structural and decorative installations. Thus, as clad materials, they are generally fabricated in thin sections and are welded throughout their total thickness with 25–20 or 25–12 (Cr-Ni) electrodes.[22, 23]

Types 304 and 308 stainless clad steels are usually welded on the stainless side with a root pass of 25–20 or 25–12 (Cr-Ni)

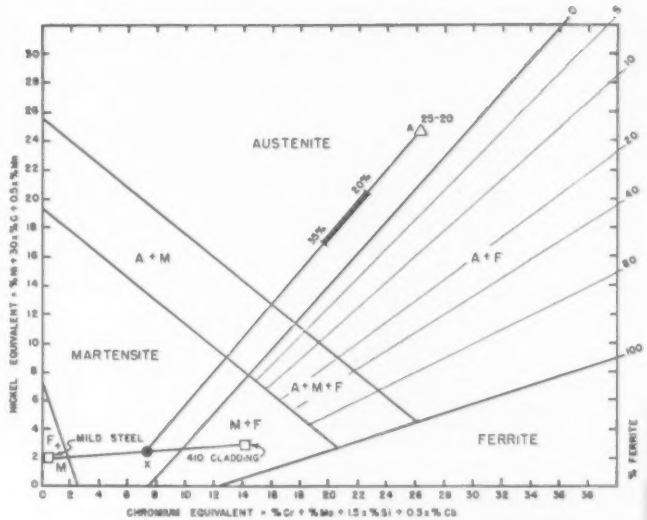



*Fig. 24 Structural diagram for weld metal illustrating the welding of Type 410 stainless clad steel with 25–20 (Cr-Ni) electrodes[3]*

weld metal which may be followed by 19–9 weld metal.[25, 39]

Stabilized Types 321 and 347 stainless clad steels are generally welded on the stainless side with a root pass from a 25–20–Cb or 25–12–Cb (Cr-Ni-Cb) electrode. This may be followed by layers of 19–9–Cb (Cr-Ni-Cb) weld metal. Because of the high crack sensitivity of 25–20–Cb (Cr-Ni-Cb) weld metal, in some cases a root pass of 25–20 (Cr-Ni) weld metal is used which is followed by deposition of 19–9–Cb (Cr-Ni-Cb) weld metal.[25, 39]

Type 309 stainless clad steels are generally arc welded with 25–20 (Cr-Ni) electrodes on the stainless steel side.

Type 310 stainless clad steels in thin sections are welded throughout with 25–20 (Cr-Ni) electrodes. Because of dilution from the carbon steel, half the thickness of the root bead should be ground off before successive layers may be deposited.

Type 316 stainless clad steels are welded with a root pass from 25–20–Mo or 25–12–Mo (Cr-Ni-Mo) electrodes. Subse-

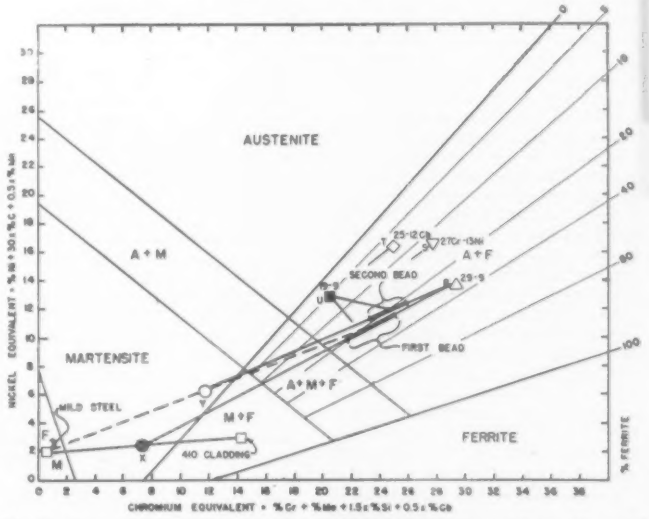



*Fig. 25 Structural diagram for weld metal illustrating the welding of Type 410 stainless clad steel with several different electrodes[3]*

quent layers may be deposited from 18–13-Mo (Cr-Ni-Mo) electrodes (also generally described as 19-9-Mo electrodes).[25, 39]

In Germany, it is not practiced to make the initial stainless-steel weld deposit with an electrode of higher chromium content, for example a 25–20 (Cr-Ni) root deposit on an 18–8 (Cr-Ni) clad plate (see Table 4).[11] Instead, all welding from the stainless clad side is made with an electrode of the same composition as the stainless-steel cladding.[11]

### *Martensitic Stainless Clad Steels*

Ordinarily, the martensitic chromium stainless clad steels (Type 410) are welded on the clad side with 25–20 or 25–12 (Cr-Ni) stainless electrodes.[5, 25, 39] These electrodes do not exhibit the brittle structure in the as-welded condition which is shown by the ferritic 18 or 28% chromium stainless weld deposits because of the high-temperature embrittlement[3] and the greater differential in coefficients of expansion. In Germany, a lower carbon partially martensitic 13% chromium steel is generally satisfactorily welded with stabilized 18–8–Cb (Cr-Ni-Cb) electrodes.[11]

Under some corrosive conditions, a chromium stainless-steel weld metal is required. In arc welding of clad plates up to a total thickness of about $^1/_4$ in., where usually only one bead is deposited on the cladding side, dilution may become a problem. In order to minimize dilution, either 18 or 28% chromium stainless-steel electrodes are recommended (Table 4).[25, 39] When, on heavier plates, the initial stainless weld deposit is covered by subsequent beads so that dilution of the surface deposits may be considered inconsequential, then 16 or 12% chromium stainless electrodes may be satisfactory.

As was discussed earlier,[3] martensitic stainless steels, such as Type 410, should be preheated between 300 and 400° F. (150 and 205° C.) and, in addition, should receive a postheat treatment between 1300 and 1400° F. (705 and 760° C.).* When straight 18% chromium electrodes are used this preheat treatment is believed[61, 62] to be particularly necessary to prevent heat-affected-zone cracking near the triple junction of the stainless cladding, the stainless weld metal and the backing steel. The postheat treatment precipitates carbides and tempers the martensite structure in the heat-affected zone. In addition, the postheat treatment is somewhat beneficial in relieving residual stresses in these dissimilar-metal joints. Results of the effects of postheat treatments at 1300° F. (705° C.) are reported in Table 6. All welds shown in Table 6 were made in the horizontal position, which resulted in a somewhat reduced ductility since this position usually requires a greater number of passes and smaller electrodes.[64] If these welds had been made in the flat position, approximately 10% additional elongation would have been obtained.[64] In any case, specimens E, F, G and H which were not stress relieved adequately met the ASME Boiler Construction Code requirements for this type of joint.[64]

The so-called modified Type 410 stainless-steel material, with 0.08% max. carbon, usually exhibits adequate strength and ductility when welded without preheat and postheat treatment—if austeni-

* Although 1300 °F. (705°C.) is generally preferred as the minimum postheating temperature, somewhat lower temperatures may also produce satisfactory results if very much longer heating periods are used.

**Table 4—Welding Electrodes Ordinarily Recommended* for Chromium and Chromium-Nickel Stainless Clad Steels[25, 39, 64, 72]**

| *Cladding* | *Cover exposed steel with 1st pass or layer* | *Complete balance of weld with* | *Alloy to steel (welds not exposed to corrosion)* |
|---|---|---|---|
| 301 | 25–20, 25–12 | 25–20, 25–12, 19–9 | 25–20, 25–12 |
| 302 | 25–20, 25–12 | 25–20, 25–12, 19–9 | 25–20, 25–12 |
| 304 | 25–20, 25–12 | 25–20, 25–12, 19–9 | 25–20, 25–12 |
| 304 L† | 25–20–Cb, 25–12–Cb | 25–20–Cb, 25–12–Cb, 19–9–Cb | 25–20, 25–12, 25–20–Cb, 25–12–Cb |
| 308 | 25–20, 25–12 | 25–20, 25–12, 19–9 | 25–20, 25–12 |
| 309 | 25–20 | 25–20 | 25–20, 25–12 |
| 310 | 25–20 | 25–20 | 25–20, 25–12 |
| 316 | 25–20–Mo, 25–12–Mo | 25–20–Mo, 25–12–Mo, 19–9–Mo | 25–20, 25–12, 25–20–Mo, 25–12–Mo |
| 316 L† | 25–20–Mo–Cb, 25–12–Mo–Cb | 25–20–Mo–Cb, 25–12–Mo–Cb, 19–9–Mo–Cb | 25–20–Mo, 25–12–Mo, 25–20–Cb, 25–12–Cb |
| 321 | 25–20–Cb, 25–12–Cb | 25–20–Cb, 25–12–Cb, 19–9–Cb | 25–20, 25–12, 25–20–Cb, 25–12–Cb |
| 347 | 25–20–Cb, 25–12–Cb | 25–20–Cb, 25–12–Cb, 19–9–Cb | 25–20, 25–12, 25–20–Cb, 25–12–Cb |
| 405 | 25–20, 25–12, 18 Cr‡ | 25–20, 25–12, 18 Cr‡ | 25–20, 25–12 |
| 410 | 25–20, 25–12, 18 Cr‡ | 25–20, 25–12, 18 Cr‡ | 25–20, 25–12 |
| 14–16 Cr | 25–20, 25–12, 28 Cr‡ | 25–20, 25–12, 18 Cr‡ | 25–20, 25–12 |
| 430 | 25–20, 25–12, 28 Cr‡ | 25–20, 25–12, 18 Cr‡ | 25–20, 25–12 |
| Lukens 20§ | 25–20, 25–12 | Carpenter 20 | 25–20, 25–12 |

* For modification and special conditions see discussion.

† The letter "L," as recently adopted by the American Iron and Steel Institute, denotes the *extra-low-carbon* (0.03% max. C) grades.

‡ Must be used under certain corrosive conditions and may require special pre- and postheat treatments.

§ Base steel clad with Carpenter 20 stainless steel.[4]

**Table 5—Recommended Welding Electrode Diameters for Stainless Clad Steels[12, 68]**

| *Sheet or plate thickness* | *Electrode diameter, in.* | *Current range, amp.* | |
|---|---|---|---|
| | | *Chromium stainless steel* | *Chromium-nickel stainless steel* |
| Under 14 gage | Up to $^5/_{64}$ | ... | ... |
| 16 gage to $^1/_8$ in. | Up to $^3/_{32}$ | ... | ... |
| $^1/_8$ to $^1/_4$ in. | Up to $^1/_8$ | 90–130 | 70–105 |
| $^1/_4$ to $^1/_2$ in. | Up to $^5/_{32}$ | 125–170 | 100–140 |
| $^1/_2$ to 1 in. | Up to $^3/_{16}$ | 160–210 | 130–180 |
| Over 1 in. | Up to $^1/_4$ | 200–300 | 240–400 |

**Table 6—Effects of Postheat Treatments (Stress Relieving) at 1300° F. (705° C.) on the Ductility of Welded* 1"-in. Thick Type 410 10% Stainless Clad Steels in the Free Bend Test[5]**

| *Specimen No.* | *Initial gage length, in.* | *Final gage length, in.* | *Difference, in.* | *Elongation, %* | *Remarks* |
|---|---|---|---|---|---|
| A | 1 | 1.30 | 0.30 | 30 | Stress relieved |
| B | 1 | 1.35 | 0.35 | 35 | Stress relieved |
| C | 1 | 1.30 | 0.30 | 30 | Stress relieved |
| D | 1 | 1.31 | 0.31 | 31 | Stress relieved |
| E | 1 | 1.22 | 0.22 | 22 | Not stress relieved |
| F | 1 | 1.20 | 0.20 | 20 | Not stress relieved |
| G | 1 | 1.23 | 0.23 | 23 | Not stress relieved |
| H | 1 | 1.24 | 0.24 | 24 | Not stress relieved |

* The clad section was welded by depositing first a 25–12–Cb (Cr-Ni-Cb) layer and, subsequently, a 19–9 (Cr-Ni) layer. Each weld-metal layer consisted of several string beads each of which overlapped the preceding bead about half the width of a bead and, in turn, was similarly overlapped by the succeeding bead. Each bead was deposited only after the plate had cooled to room temperature.[5] Ordinarily the welds would have been made with 25–20 or 25–12 (Cr-Ni) electrodes.

tic electrodes are used.[64]

A typical heat-affected-zone crack in a Type 410 martensitic stainless steel welded with a 16% chromium stainless electrode is shown in Fig. 26. The specimen had not been preheated.[63] Although this specimen had also not received a postheat treatment, others which received a postheat treatment of 1 hr. at 1200° F. (650° C.) showed similar cracks if they were not preheated.[63] For best practice the weld should have been made with 25–20 or 25–12 (Cr-Ni) weld metal.

Under extremely unfavorable welding conditions, which introduce severe restraint, special welding procedures may have to be employed on heavy sections. For example, 1¼-in. thick Type 410 clad plates were welded in the horizontal position (single V-joint) by first welding the mild-steel portion with E6013 mild steel electrodes.[8] The clad portion then was welded by depositing two layers of stainless weld metal. The first layer was made with stabilized 25–12–Cb (Cr-Ni-Cb) electrodes and the second or outer layer was made with 19–9 (Cr-Ni) electrodes. Each layer consisted of several string beads each of which overlapped the preceding bead by about half the width of a bead and, in turn, was similarly overlapped by the succeeding bead. Moreover, each bead was deposited only after the plate had cooled to room temperature. The elongations of free bend specimens with the stainless cladding on the tension side are given in Table 6. Stress relieving at 1150° F. (620° C.) raised these elongation values from over 20 to over 30%.[8] Instead of a root bead from a 25–12–Cb (Cr-Ni-Cb) electrode, 29–9 (Cr-Ni) or 25–20 (Cr-Ni) electrodes with 0.15 to 0.20% carbon might also have produced satisfactory root deposits.[8]

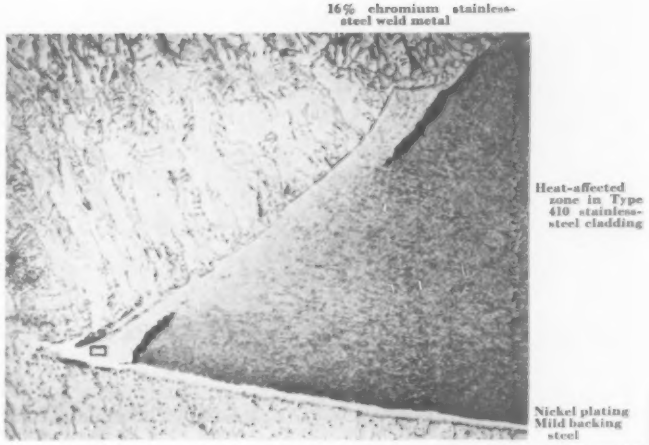

16% chromium stainless-steel weld metal
Heat-affected zone in Type 410 stainless-steel cladding
Nickel plating
Mild backing steel

*Fig. 26 Triple junction of 16% chromium stainless steel weld metal, Type 410 stainless steel cladding and mild steel backing which shows cracks in heat-affected zone. Specimen taken from plate which was neither preheated nor stress-relieved.*[63] *Magnification 40 ×. (Etchant: 10% Hydrochloral-electrolytic)*

### *Ferritic Stainless Clad Steels*

Like the martensitic types, ferritic stainless clad steels ordinarily are welded with 25–20 or 25–12 (Cr-Ni) stainless electrodes.

When certain corrosive conditions require a chromium stainless weld metal, the use of chromium stainless electrodes containing at least 16% chromium is generally recommended. When dilution has to be considered in single weld metal deposits on thin clad plates, the welding electrode should contain at least 4% more of chromium than the cladding material in addition to the extra quantity of chromium added by the electrode manufacturer to compensate for oxidation losses.

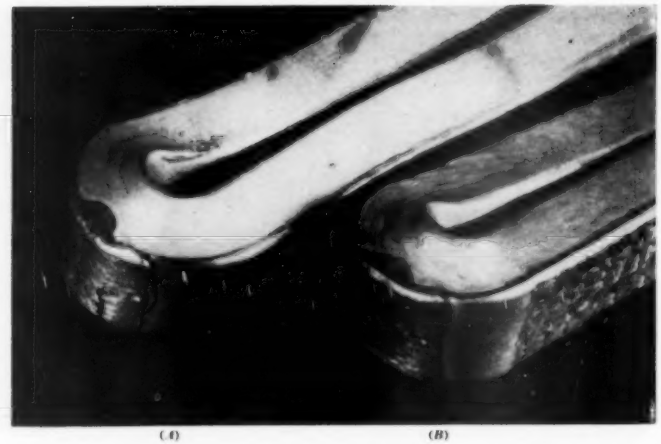
Preheat treatments are generally not necessary on ferritic stainless clad steels welded with 16 or 18% chromium stainless electrodes. On the other hand, when high-chromium stainless electrodes (over 25% chromium) are used, preheat treatments between 300 and 400° F. (150 and 205° C.) are advisable.[3] Because ferritic stainless weld metal tends to be highly brittle in the as-welded condition, a postheat treatment between 1300 and 1400° F. (705 and 760° C.) is generally essential if ductility and toughness are desired in the welded joint.[3, 22, 53] Even when austenitic stainless-steel electrodes are used the as-welded ferritic stainless steel cladding may lose sufficient ductility in the heat-affected zone to crack in this zone when tested in the conventional bend test. When postheat treatments cannot be given to the weldment the prevention of this embrittlement may require special welding procedures. Typical results are illustrated in Fig. 27 (*A*) and (*B*). Each specimen was made from a 20% clad Type 430, ½-in. thick plate.[64] A ⅛-in. wide, ⅛-in. deep groove was machined on the clad side. Specimen (*A*) was manually welded in 2 passes with 5/32-in. diameter 25–12 (Cr-Ni) electrodes at a current of 135 amp.[64] A sketch of the weld is shown in Fig. 28 (*A*). Pre- and postheat treatments were not used.[64] In the transverse free-bend test this specimen showed an elongation of 28% and failed as shown in Fig. 27 (*A*).[64] Specimen (*B*) was also manually welded but in 4 passes, as sketched in Fig. 28 (*B*), with 25–12 (Cr-Ni) electrodes and a current setting of 135 amp.[64] This specimen showed a 41.3% elongation in the transverse bend test and did not crack.[64] The satisfactory heat-affected zone ductility of Specimen (*B*) was due to the final annealing bead (No. 4) which reduced the embrittlement and as such served the same function as the beneficial postheat treatment at about 1350° F. (730° C.). Similar results are obtained when the welds are made with 25–20 (Cr-Ni) electrodes instead of the 25–12 (Cr-Ni) electrodes illustrated in Figs. 27 and 28.[64]

### *Code Requirements*

In the *Interpretations to the ASME Boiler Code*[41] considerable emphasis is given to welding procedures and to the qualification of welded joints in vessels which are constructed under the ASME Boiler Code rules.

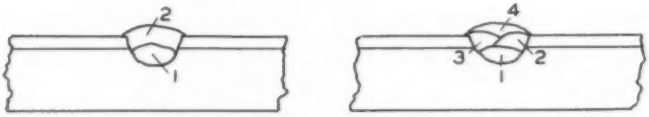
When the design of the vessel is based upon the full thickness of the composite plate, test plates from clad material of the same grade as the vessel must be welded, cooled and must receive the same heat treatments (if heat treatments are used) as employed in the production of the vessel. Duplicate bend specimens must be bent with the clad surface in tension and in compression. Moreover, standard all-weld-metal 0.505-in. tension tests are to be made which contain no cladding along the gage length—unless sufficient base metal is not available, in which case the tensile test may be omitted.

When the design of the clad section is based upon the backing-steel thickness alone, the weld may be qualified as above or the welding of the stainless cladding side may be qualified separately from the welding procedure of the joint in the backing steel. In the latter case suitable test plates shall be prepared by making a welded joint between the edges of the cladding along a chipped groove in a clad plate or between two strips of stainless-steel material which are held in contact with a separate base plate not less than 3 in. wide by 6 in. minimum length. For qualification of the welding procedure for the gap between the cladding, the width of the gap shall be the maximum gap to be



(A) (B)

*Fig. 27 Photograph illustrating the effect of welding procedure upon the bend ductility of the heat-affected zone in 20% Type 430 stainless clad steel specimens welded with 25–20 (Cr-Ni) electrodes. (A) Two-bead procedure and (B) four-bead procedure with final "annealing" bead*[64]




(A) (B)

*Fig. 28 Sketches illustrating welding procedure used in the preparation of the bend-test specimens shown in Fig. 27. (A) Two-bead procedure and (B) four-bead procedure with final "annealing" bead*[64]

used in the construction, but shall not be over 3/4 in. and not less than twice the nominal thickness of the cladding. Subsequent to welding, the cooling and heat-treating procedures must be the same as those to be used on the vessel. The weld reinforcement must be removed flush with the surface of the cladding material. Two suitable longitudinal bend specimens, with the weld approximately midway between the sides, are required to be bent with the cladding in tension.

Special qualification tests are also required of each welder.

It is also required that the steel weld metal deposited from the backing-steel side is not fused with and diluted by the stainless steel.

Radiographic examination, when it is required, must be made of the completed weld (including the cladding) when the full thickness of the composite plate is used in design calculations or of the base-plate weld (before the weld in the cladding is made) when only the base-plate thickness is used in the design calculations.

Radiographic examination is required when steels clad with straight chromium-stainless steels that are in contact with base plate welds are also welded with straight chromium stainless-steel welding electrodes. Radiographic examination may not be required when austenitic welding rods are used for welding the clad straight chromium stainless steels.

Many special and additional requirements and recommendations are also discussed in the Interpretations.[41]

## FLAME CUTTING

Stainless-clad plates less than 5/8 in. thick are generally sheared. When flame cutting is used, it is preferable practice to chip through the cladding to the steel with a round-nosed chisel and flame-cut from the clad side through the chipped groove.[66] Specially cored metallic electrodes are also being used through which air or oxygen is burned. Although cutting is readily accomplished by this process, an oxidized edge will remain which must be ground by at least 1/8 in. to remove deteriorated metal.[66]

On plates over 5/8 in. thick, cutting is usually performed from the backing-steel side with a suitable flame-cutting torch. By cutting from the carbon-steel side the resulting iron-oxide slag stream is utilized as a fluxing agent to overcome the oxidation resistance of the alloy cladding and to permit progressive cutting action. Although it has often been recommended that the torch head should be inclined from about 5 to 20 degrees from the perpendicular with the tip pointing toward the completed part of the cut,[10, 13, 14, 24, 27, 44, 47, 48, 65, 73] it is now considered better practice to leave the torch head perpendicular.[64] The oxygen cutting pressure should be reduced considerably under the pressure used for mild steel to avoid undercutting and "blow-back" at the bond between the carbon steel and the stainless cladding. Recommended values are given in Table 7. The table has been primarily developed for equipment using high purity oxygen and 1150 Btu natural gas.[64] However, it is believed that the recommended values can also be applied to most of the other flame-cutting gases.

Preheating at the start of the cutting operation is generally necessary when natural gas or propane gas is used for cutting plates heavier than 1/2 in. since the low pressures at which these gases are supplied do not heat the plate sufficiently. A three-hose cutting torch should preferably be used where separate preheat and cutting-oxygen hoses allow individual regulator controls. Generally 50 psi. oxygen and 20 psi. natural gas pressures are sufficient. The final flame setting is made by means of blowpipe valve manipulation and is governed by such factors as plate-surface condition, composition of backing and cladding materials, etc. Be-

**Table 7—Flame Cutting Clad Stainless Steels*** [64]

| *Plate thickness, in.* | *Cutting speed, in./min.* | *Cutting —pressure, lb.— Min.* | *Max.* | *Cutting orifice (Oxweld) diameter, in.* | *Cutting orifice (Airco) diameter, in.* | *Airco tip size* |
|---|---|---|---|---|---|---|
| 3/16 | 22–25 | 5 | 7 | 0.04 | 0.0430 | 0 or 1 |
| 1/4 | 19–21 | 6 | 8 | 0.04 | 0.0430 | 1 |
| 3/8 | 16–18 | 7 | 10 | 0.05 | 0.0520 | 1 or 2 |
| 1/2 | 15–17 | 7 | 12 | 0.07 | 0.0700 | 4 |
| 5/8 | 14–16 | 8 | 13 | 0.08 | 0.0785 | 4 or 5 |
| 3/4 | 13–15 | 9 | 14 | 0.08 | 0.0785 | 5 |
| 1 | 12–14 | 10 | 16 | 0.10 | 0.1065 | 6 or 7 |
| 1 1/2 | 10–12 | 12 | 18 | 0.12 | 0.1250 | 7 or 8 |
| 2 | 9–11 | 12 | 18 | 0.16 | 0.1660 | 9 or 10 |
| 2 1/2 | 7–9 | 16 | 24 | 0.16 | 0.1660 | 9 or 10 |

* This table is for natural gas. For use of acetylene, the next larger tip size is recommended.

cause of the low cutting pressures, the nozzle height is quite critical and should be adjusted so that the inner cone of the flame nearly touches the plate surface.[63]

Increased speeds without danger of losing the cut are possible when cutting plates $\frac{1}{2}$ in. thick or less by leading the cutting nozzle by approximately $1\frac{1}{2}$ in. with a preheater nozzle. This is best accomplished by means of attaching a double beveling adaptor (standard equipment of most suppliers) to the cutting torch to hold both nozzles in line. Additional hoses or connections are not required when this setup is used. The preheat nozzle is readily made by plugging and silver soldering the cutting oxygen passage of any nozzle of suitable size. The preheating arrangement also serves as a descaler.[64]

It is also possible to flame cut from the clad side through a groove chipped in the cladding.

## SERVICE FAILURES

Some of the factors which contribute to defects in stainless clad steels already have been discussed. Most failures can generally be attributed to defects in the weldments which usually could have been prevented by good workmanship or by correct selection of materials. The commercial clad stainless steels usually are quite sound unless proper bonding was not accomplished during the manufacturing process.

Often these defects are quite small and may not be revealed by ordinary testing procedures. However, service conditions may aggravate these small defects and, in time, cause the vessel or structure to fail.

Recently several reactor vessels in the catalytic-cracking units of three oil refineries, constructed from $1^3/_8$-in. thick Type 347 stainless clad steel plates produced by the intermelting process, were found to contain cracks in the carbon-steel portion adjacent to the main seam welds after about 60,000 hr. service between 900 and 1000° F. (480 and 540° C.)[78, 80] Examination of suitable samples from the cracked regions revealed an extensive system of intergranular cracks oriented normal to the plate surface and characteristic of so-called "stress-to-rupture" failures.[80] The cracks generally appeared in the heat-affected zone of the welded joints and along the junction between the carbon base steel and the stainless-steel repair welds.[79] It is believed that they all were initiated near the edge of the weld overlay on the plate surface.[80] In addition to the widespread intergranular cracking, it was also observed that graphitization, as well as carbide spheroidization, had occurred in the aluminum-killed backing steel.[80] The graphite was in most cases of the scattered nodular type and was present in both the base steel and in the heat-affected zones. Only a few specimens showed very heavy concentrations of nodular graphite in the heat-affected zones in a form which could be termed "continuous nodular" or "bead type". Chain graphitization, with the possible exception of one isolated specimen, was not found.[80]

Although graphitization was likely to have been a contributory factor, detailed examination of appearance of the cracks suggests that the predominant cause of failure has been the stress state generated at the welds by restraints and by stress concentrations which have been aggravated by the differences in the coefficients of thermal expansion between the carbon steel and the stainless-steel cladding and weld metal.[79, 80]

Service exposures at temperatures which embrittle the stainless cladding should also be prevented. These conditions are determined by the metallurgical characteristics of the stainless materials itself. They have been discussed previously.[1–3]

## APPLICATIONS

There are many applications where stainless clad steels and applied liners are used as substitutes for the more expensive solid stainless steels. Many typical examples can be found in petroleum refineries, in the chemical industry, in paper mills, in milk tanks[37] and in many other vessels, containers, pipe lines, etc.

In a number of applications stainless clad steels and/or applied liners supply unique qualities or properties of their own. In the way of illustration, an important unit in its operation expels exhaust gases while being immersed in salt water, thus encountering two different corrosive conditions. A double clad steel has been developed for this purpose, with the carbon steel in the center.[70]

## ACKNOWLEDGMENTS

Major contributions were received from: K. Bungardt, Deutsche Edelstahlwerke A.G.; L. K. Dawson, Lukens Steel Co.; F. H. Keating, Imperial Chemical Industries, Ltd.; W. L. Keene, Superior Steel Co.; C. H. Samans, Standard Oil Co. (Indiana); M. A. Scheil, A. O. Smith Corp. and L. W. Williams, Lukens Steel Co. In addition useful comments and information were also supplied by: H. S. Blumberg, M. W. Kellogg Co.; F. W. Davis, United States Atomic Energy Commission; J. Erskine, Colvilles, Ltd.; W. B. Hoyt, M. W. Kellogg Co.; J. G. Kerr, C. F. Braun & Co.; G. F. Lockeman, Procter & Gamble Co.; R. F. Miller, United States Steel Co.; A. L. Schaeffler, Allis-Chalmers Mfg. Co.; and R. D Thomas, Jr., Arcos Corp.

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# Performance of Weldments

(*Continued from page 141-s*)

Some points presented in the paper are not entirely clear and further comment by the authors would be helpful; for example, the meaning of the brackets in the fracture photos, also the travel speeds used in making the welds, and whether the longitudinal and transverse strains $1^1/_2$ in. from the weld center line showed the same trend as the thickness strain; also, does the fracture appearance correlate with the 1% thickness reduction criterion of brittle performance and the 10% criterion of ductile performance?

It is pleasing to discover that the authors have slipped in a bit of humor in this scientific paper, which presumably is a consequence of the politica latmosphere in which the investigation was undertaken. In the section on "Fracture Characteristics of E12016-HTS Weldment" it is amusing to note that the atomic fracture paths are given the power of *electing* to propagate along one direction rather than another.

Finally, we hope that the authors will extend their work to include a study of the origin of fracture in terms of specific structure zone, and the resistance to fracture propagation by graded explosion impact energies.

## *Authors' Reply*

Dr. Aborn's comments relative to our first progress report on the fracture performance of full welds are greatly appreciated. The comments indicate an interest in further application of these test methods which the authors share and anticipate. The question of the role of natural notches due to the presence of weld reinforcement, microstructural effects due to variations in welding practice or postheat treatment, embrittling effects due to aging developed in the various weld types and other practical questions are very much in need of critical investigation. Inasmuch as the present investigation represented the first step toward a general understanding of weld performance, it was deemed necessary to eliminate complicating factors such as weld reinforcement. In this regard, it should be recognized that weld reinforcement cannot be treated as a fixed condition in that reinforcement introduces a number of variables; e.g., type of ripple, contour and intersect angle at fusion line. By conducting the initial study with a fixed condition (all welds ground smooth), a reference base line was established for future evaluation of the specific effects of reinforcement variables—such investigations are in process.

In regard to the question raised as to whether prime plate tests were carried to a sufficiently low temperature—an absolute level of 1% strain-at-fracture was not obtained in the case of the prime plates; accordingly the transition band was denoted as extending somewhat below the −105° F. temperature. The fact that 1% strain-at-fracture values were obtained for the E12016 weldments at −105° F. is not in itself sufficient to ascribe somewhat better performance to the prime plate without consideration of the fact that at this temperature fractures of weldments initiated with equal frequency in plate and weld. Thus, the fracture data support rather conclusively the indications of equal performance given by the transition curves.

The brackets on the fracture pattern photographs were intended as a guide to the reader indicating the fracture surfaces which were photographed. The welds were made manually with a progression of approximately 4–6 in. per minute depending on the pass and weave.

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# Biaxial Fatigue Tests on Flat-Plate Specimens

***A method of obtaining data on plate materials under cyclic biaxial stress conditions at minimum cost***

*by R. U. Blaser, J. T. Tucker, Jr., and L. F. Kooistra*

**Abstract**

In this paper is described a method of materials testing simulating the state of stress encountered in pressure-vessel service. This method was developed to obtain data on plate materials under cyclic biaxial stress conditions at minimum cost.

Due to the high cost of cylindrical specimens it is difficult and expensive to obtain adequate data on the performance of plate materials for pressure vessels. The test described effectively bridges the gap between prohibitive specimen cost and representative plate surface conditions and state of stress.

In the test the rectangular plate is freely supported on the edges, while it is uniformly loaded on one side by means of oil hydraulic pressure. Cyclic conditions are set up by periodic pulsation of the oil pressure.

An experimental stress analysis is given for a $^{3}/_{4}$-in. thick specimen. Methods of detecting initiation of rupture are discussed as well as the final appearance of the fatigue fracture.

## INTRODUCTION

THE design of modern steam plants and certain types of process equipment has followed a general trend toward increased capacity, pressure and temperature. As a result, pressure vessels have been increased in design pressure and in diameter to the point where shell and head thicknesses are becoming excessive. The many difficulties in handling, forming and inspecting such heavy plate are approaching a practical limit of manufacturing procedure in even the most modern plants. In addition, operational difficulties, such as thermal stresses resulting from starting up or shutting down equipment, will increase as the thickness of the plate is increased.

Many pressure-vessel designers believe that one possible solution to the problem is the use of high-tensile, high-yield alloy steels in conjunction with design stresses that are higher than present code limitations. It is anticipated by some that available high-tensile alloy-steel plate can be used safely and economically with design stresses of $^{1}/_{2}$ to $^{2}/_{3}$ of the yield point if the vessel is properly designed, constructed and operated under specific and controlled conditions. However, vessels of this type should not be designed on opinion or compromise but should be the product of careful research.

The Pressure Vessel Research Committee of the Welding Research Council has been quite active in investigating this subject. A Special Committee on Increased Design Stresses was formed to study this matter with the purpose of determining realistic design stresses, higher than present code limitations, for use in special applications.[1] As part of the proposed program model vessels containing a number of variables, such as nozzle attachments, openings, head shapes, welds, materials and manufacturing procedure, would be studied.

Such points of stress concentration have been the subject of individual as well as cooperative investigations and many theoretical analyses have been developed. Experimental work on pressure vessels has been in progress in the authors' company for years. The development of new techniques has resulted in quantitative data which have been published.[2,3] The use of such strain-gage test methods has covered a wide range in pressure-vessel design and size.[4,5]

Knowledge of how a pressure vessel or a specific material will react to a known stress distribution is also required to determine suitability for expected service conditions. A test to destruction by static pressure is easily accomplished but has several features which are not applicable to operating conditions. The distortion from plastic flow prior to failure often results in a shape much different from the vessel in operating condition. The large amount of plastic deformation is so far beyond the operating strain range that the properties of the material change greatly. Therefore, in the final stages of a static-pressure destruction test neither the shape nor the material is the same as the vessel it is desired to test.

For these reasons considerable work has been done on fatigue testing.[3-6] The hydraulic fatigue test does not distort the vessel and may be relied upon to show the existence of any important stress raisers. The

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fatigue work of H. F. Moore and the authors' company many years ago helped to justify to Code bodies the use of welding in pressure-vessel manufacture.[6] The fatigue test reveals the comparative suitability of different materials, with or without typical stress raisers, to operate satisfactorily at high stress levels. In satisfying this requirement, a successful fatigue test of a predetermined number of cycles will establish confidence that a particular material or design will be satisfactory in service.

The many variables in types of stress concentration and in possible materials make the time and expense elements become almost prohibitive if full-size or model vessels are used for all tests. Thus it becomes obvious that a simpler testing procedure would be of considerable value. Study of the various stress-concentration points in a pressure vessel, such as the bending of head knuckles under pressure, led to the consideration of a bending type specimen. In order to retain a two-dimensional stress system, a flat-plate specimen freely supported on its edges and deflected by hydraulic pressure was chosen. The apparatus developed and the method of testing this type of specimen will be discussed.

## DESCRIPTION OF APPARATUS

One unit of the biaxial fatigue apparatus with its fatigue fixture completely assembled is shown on Fig. 1.

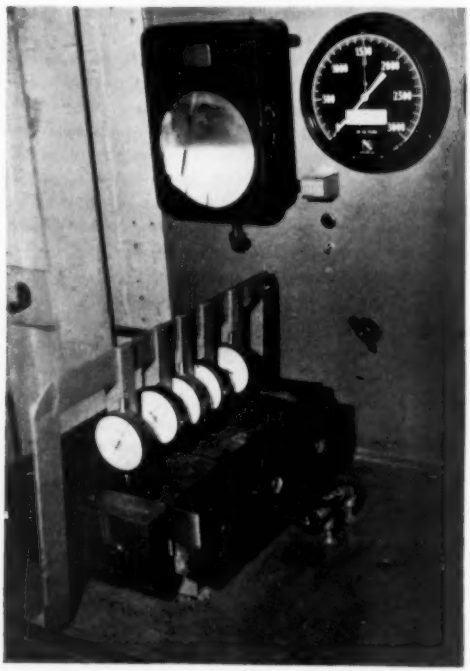

*Fig. 1 General view of fatigue apparatus*

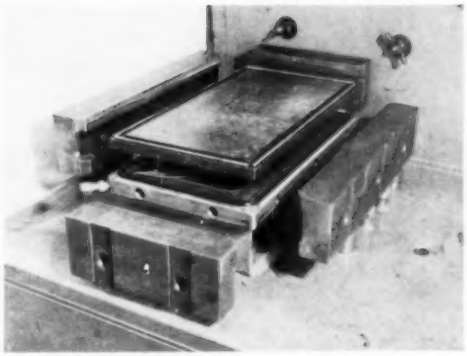

*Fig. 2 Expanded view of biaxial fatigue fixture*

The instruments for measuring and controlling the fatigue cycles are mounted on the panel behind this fixture along with the cycle counter and the control valves. A supply reservoir, pump and other auxiliary equipment are located in the space beneath the table top.

### *Fatigue Fixture*

The expanded view of the fatigue fixture shown on Fig. 2 clearly defines its individual parts and their order of reassembly. Four C-shaped clamping bars hold the rectangular flat-plate specimen and the back-up plate face to face with an O-ring gasket sealing the periphery of the space between them. The flat-plate specimen is thus freely supported since its edges are held between the four hardened steel rods located in the V-grooves in the inner surface of the clamping bars

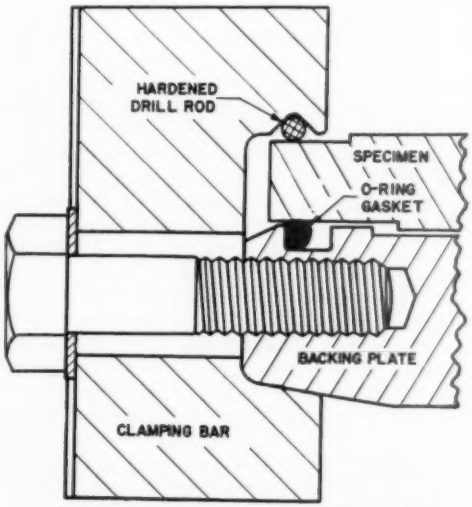


*Fig. 3 Section through edge of fatigue fixture*

and the O-ring gasket which offers little or no axial restraint. Details of the specimen support are illustrated on Fig. 3. This is a section taken through the edge of the assembled fatigue fixture.

A threaded connection in the heavy backup plate is used to admit pulsating pressure cycles into the space between the plates thus causing cyclic bending stresses in the specimen. This same connection also contains a pressure tap for the gage which measures the operating pressure in the space between the plates.

The fitting threaded into the left-hand corner of the backup plate is a pressure-tight inlet for three copper wires to an AX-5 strain gage cemented on the center of the inside surface of a specimen. This gage measures the stress range imposed on the specimen during each fatigue cycle leaving the center area on the outside surface free for inspection.

### *The Specimen*

The specimens used with this fixture were designed according to the formulas derived by Timoshenko and Lessells[1] for the maximum and minimum stresses in the center of a rectangular plate freely supported at the edges and having a uniformly distributed load over one surface. In such a specimen the ratio of the two principal stresses on the surface at the center of the plate can be varied widely by changing the dimensions of the rectangle. Another advantage of the flat-plate specimen may be gained by obtaining the material in the proper thickness so that the as-received surfaces can be used with a minimum of preparation. The metallurgical condition of the plate can also be maintained.

The flat-plate specimens are burned to a rectangular shape with an oxyacetylene flame-cutting machine. This method used with a reasonable amount of care will produce plates of sufficient accuracy that no further machining of the edges is necessary. After the plates are stress relieved (if required) according to standard pressure-vessel procedure, they are placed in a jig support on a milling machine, and the periphery of the top and bottom surfaces of the plate is machined to the shape shown on Fig. 3. These two surfaces are machined parallel, providing uniform thickness around the edge of the specimen insuring a continuous support against the hardened drill rods and a uniform compression of the O-ring seal. This machining also eliminates any difficulties from variations in plate thickness and from small amounts of plate warpage. A ground spot at the center of the bottom surface for an AX-5 strain gage and the removal of mill scale or other special preparation of the center area of the outside surface completes the specimen.

Many of the variables affecting pressure-vessel design that may be investigated with this type of flat-plate specimen are listed below:

1. A comparison of the suitability of various materials for a given application with the center areas of all plates having an identical and uniform finish.
2. A comparison of the same materials using the as-received surfaces to show effect of stress raisers resulting from various manufacturing procedures.
3. The effect of known stress raisers such as Izod notches on these materials.
4. The effect of stress-relieving or heat treatment on these materials.
5. The effect of welding the materials (girth and longitudinal seams).
6. A study of special welding techniques.
7. The effect of stress-relieving on the above-mentioned welds.
8. The effect of various atmospheres on the fatigue life of the specimens.
9. The effect of different ratios of principal stresses.
10. Comparison of biaxial fatigue limits with uniaxial fatigue properties.

### *Auxiliaries*

A diagrammatic sketch of the pressure circuit and controls is shown on Fig. 4. The gear-type pump moves an oil with a high dielectric constant in the directions of the arrows. At the beginning of a cycle the free-vane-type pressure controller closes a relay causing the magnetic starter to operate the pump. Oil is drawn from the supply reservoir through the filter and into the pump which builds up the pressure in the high-pressure circuit and the fatigue fixture. When this pressure reaches the setting on the pressure controller, a relay stops the pump and opens the solenoid valve releasing the pressure from the fixture and returning the oil to the supply reservoir. As the pressure falls off, the free vane on the pressure controller moves back to zero operating a relay which closes the solenoid valve and starts the pump for the next pressure cycle.

The throttle valve serves as a by-pass around the solenoid valve and is used on the initial cycles to prevent excessive pressure on the specimen while the proper setting of the pressure controller is obtained. After the control point is set, the throttle valve is closed

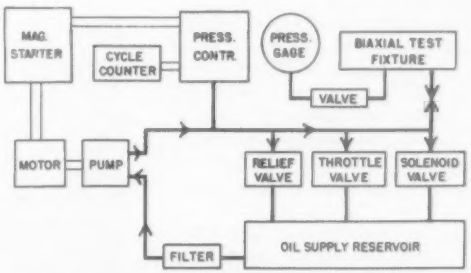


*Fig. 4 Diagrammatic sketch of biaxial fatigue testing apparatus*

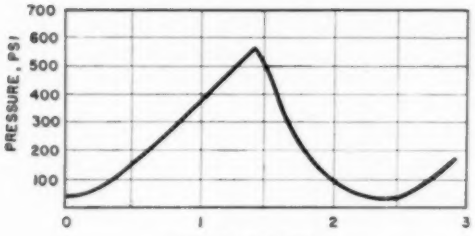


*Fig. 5 Typical pressure cycle*

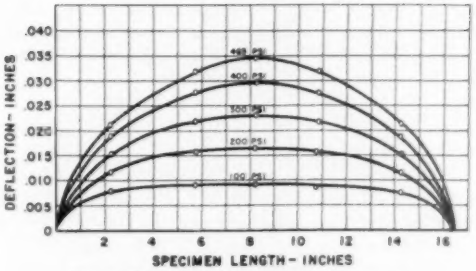


*Fig. 6 Specimen deflection with pressure*

completely so that the specimen will be cycled at its maximum rate.

Severe overloads on the specimen because of difficulty with the pressure controller or the solenoid valve are prevented by the relief valve which is set somewhat higher than the operating pressure. Other features of the circuit are an electric cycle counter operated by the pressure controller and a shut-off valve in the gage line to prevent wear on the gage between pressure readings.

A typical pressure cycle produced by this apparatus is shown on Fig. 5.

## TEST PROCEDURE

Before assembling a flat-plate specimen in the fatigue fixture, its thickness is measured, and it is given a very thorough magnaflux examination to be certain that there are no defects present and that any defects found during the test are caused by the fatigue cycles. If no defects are found, an AX-5 strain gage is cemented to the center of the bottom surface of the specimen with the axes of the gage on the center lines of the plate. After thorough drying, the gage is connected to the three lead wires that pass through the pressure-tight plug to the strain indicator on the outside. All pressure lines and bourdon tubes are vented, and the surface of the backing plate is filled flush with oil to prevent trapping any air in the system. The flat-plate specimen is then placed in position on the O-ring gasket, and the excess oil is forced out by the raised face on the bottom of the specimen.

The four C-shaped bars shown in Figs. 2 and 3 are pulled into position by the assembly bolts thus clamping the specimen between the hardened drill rod and the O-ring gasket. As the bolts are tightened, the slope at the bottom of the clamping bar slowly compresses the O-ring gasket the proper amount for initial sealing. When the bolts are tight, the backing plate is held fixed against the clamping bars maintaining the gap between the backing plate and the specimen close enough to prevent the extrusion of the gasket under pressure. Spacers are used at the corners between the edges of the specimen and the clamping bars to center the specimen in the fixture.

After assembly, strain data at various increments of pressure up to test pressure are recorded from the AX-5 strain gage on the bottom surface of the specimen to determine the range of stress present during the fatigue cycling and also to find the point at which yielding first occurs. The apparatus is then started and adjusted for the predetermined stress and pressure loads, and the fatigue test is under way.

Fatigue cycling is continued at a rate of 25 cycles per minute until magnaflux inspection reveals fatigue cracks in the outer specimen surface. The detection of the first crack is considered the failure point. However, the cycling is continued to make certain that the detected crack will propagate before a test is discontinued. The specimen is magnafluxed every 6000 cycles using the clamping bars as contacts for the electrodes to prevent damage to the specimen. Commercial magnaflux equipment using approximately 500 amp. is employed in the inspection work.

The procedure followed on the first test specimen used in developing this testing method included a

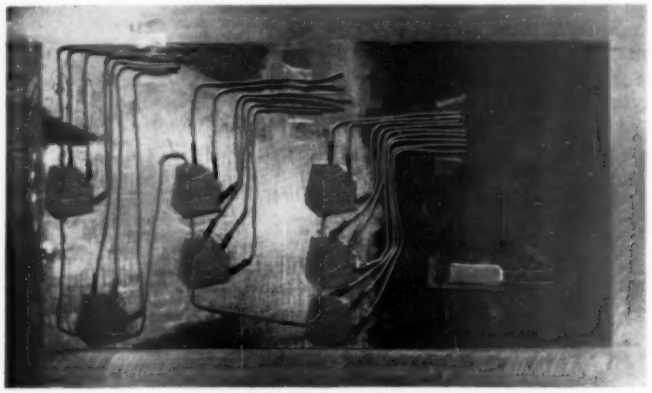

*Fig. 7 SR-4 rosettes on inside surface of specimen*

complete strain-gage analysis on the inside and outside surfaces of one quadrant of a specimen, the use of brittle lacquers, and the measurement of plate deflections with dial gages.

## DISCUSSION OF RESULTS

Some of the test results on the initial specimens are presented to demonstrate the uniform behavior of the flat-plate specimen under pressure loading and to establish its reliability as a testing technique. The initial specimens tested were made from SA-212 plate with an over-all size of 10 by 17 by $^3/_4$ in. thick.

The data taken during these tests included the measurement of specimen deflection versus pressure using the dial gage rack shown on Fig. 1. These deflections plotted on Fig. 6 indicate good correlation with the different pressures at which they were taken. It will also be noted that the curves are quite symmetrical along the line where the dial gages were placed and indicate no irregularities such as might result from edge moments. Deflections taken with a single dial gage at each intersection of $^1/_2$-in. grid lines on one quadrant of the specimen showed the same uniformity of deflection and indicated that the specimen assumes an elongated dome shape under load. The measured deflections checked the theoretical values at the center within 3%.

Electrical resistance wire strain gages of the SR-4 rosette type were used to measure the magnitude and indicate the direction of the stresses on one quadrant of a specimen. Gages were attached directly opposite one another on the inside and outside surfaces of the specimen at the locations shown on Fig. 7. The analysis of the experimental data checks quite well with the theoretical calculations. This agreement is illustrated graphically on Fig. 8, where the solid lines show the theoretical values of the principal stresses at the center of the specimen as a function of the pressure. The points enclosed in circles on these curves are the stresses determined from the experimentally measured strains. Also note the approximate two-to-one ratio of the maximum and minimum stresses at the center of the specimen which is the stress ratio designed into the specimen.

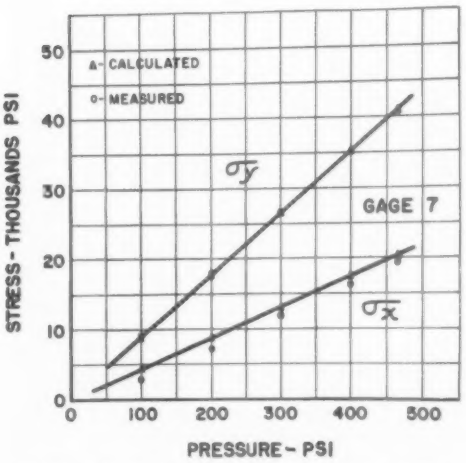


*Fig. 8 Principal Stress at center of specimen versus pressure*

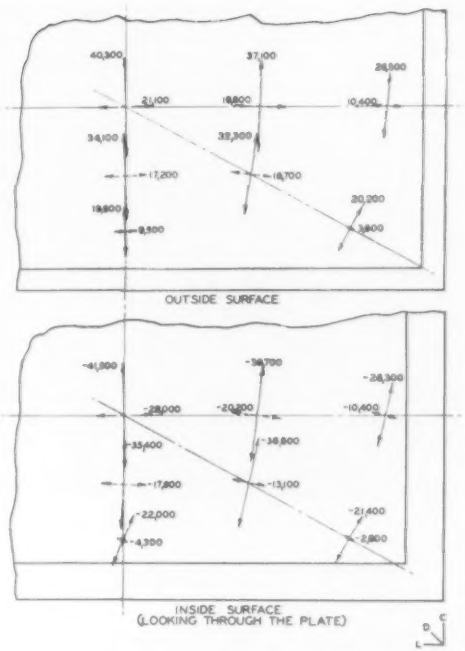


*Fig. 9 Apparent stresses on inside and outside surfaces of specimen*

Figure 9 shows a typical set of apparent stress values and their directions on the inside and outside surfaces of a specimen. It will be noted that the stresses of similar locations on the inside and outside surfaces are of almost equal value and are opposite in sign indicating that the loading of the specimen is essentially pure bending. A very good correlation is shown between the measured stresses of 40,300 psi. and −41,500 psi. at the center of the specimen and the theoretical stress of 41,000 psi. computed for the same pressure. The two-to-one ratio of the principal stresses at the center of the specimen is again demonstrated and is shown to extend over a considerable area of the specimen surface.

There was some concern that a rectangular flat-plate specimen might have high stresses at the corners or along the edges that would cause failure or disturb the desirable pattern of stresses in the center of the specimen surface. Brittle-lacquer technique was used on the outer specimen surface to show up any unexpected locations of high stresses or other discontinuities.

*Fig. 10 Stress-coat pattern on one quadrant of specimen*

The resulting stress-coat pattern on one quadrant of a specimen is shown on Fig. 10. In the center area of the specimen the lines of the stress-coat pattern are close together and run parallel to the long specimen dimension. As the ends of the specimen are approached, these lines turn toward the corners and diverge, indicating lower stresses at the corners. The stress-coat pattern was similar in all quadrants and showed a gradual change in stress distribution with lower stresses at the corners and along the edges (roughly 50% lower by strain measurement). Therefore, no difficulty is expected from the corners and edges of the specimen during fatigue testing and to date none has been encountered.

A study of the stress-coat patterns and the strain-gage results reveals that we have the very desirable condition of an appreciable area in the center of the plate of slowly changing stress levels with the proper ratio of principal stresses. Figure 11 displays what might be described as a stress contour map, giving the shape and size of stress areas. The lines in this figure connect points where the maximum stresses are equal as determined by strain-gage measurements. This clearly illustrates that an appreciable area in the center of the specimen has practically the same stress and is therefore suitable for special treatment or observation to determine the effect of different variables on fatigue life.

Various methods of nondestructive examination were used to determine the best procedure for observing and evaluating initial specimen failure. Fluorescent liquid technique, Dy-Chek, and magnaflux inspection were all tried, and in our opinion the magnaflux inspection proved to be the most satisfactory. Very fine cracks less than $^1/_8$ in. in length were detected easily by passing 500 amp. through the test fixture using the clamping bars as contact points for the electrodes. Figure 12 is a photograph of the center area of a specimen at one stage of inspection. Magnetic particles show some of the fatigue cracks that have already progressed, but it also picks up some of the very fine cracks that are just beginning.

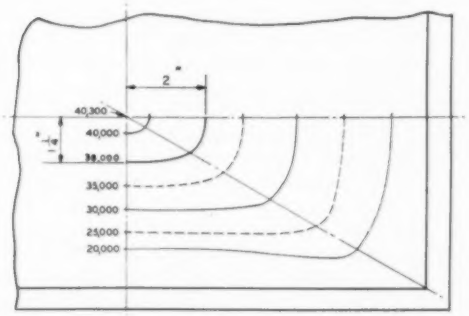


*Fig. 11 Lines of constant stress showing that appreciable area in center of plate is near maximum stress*

*Fig. 12 Magnaflux detection of cracks in specimen*

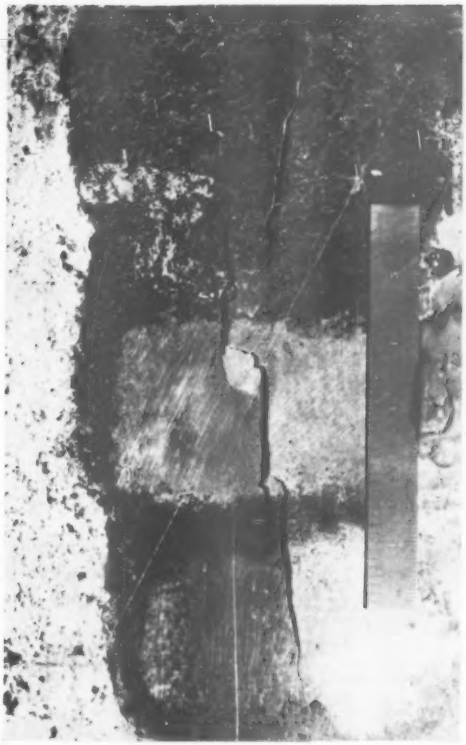

*Fig. 13 Complete specimen rupture*

The first indication of a fatigue crack should be used as the criterion determining the time or number of cycles to failure. However, to determine the mode of failure of a plate specimen in bending and to determine the hazard which might exist from such a failure, the first specimen was continued under test until the crack had propagated entirely through the thickness. At this stage of the test the fatigue cracks in the specimen appeared as shown on Fig. 13. The four major cracks had propagated through the thickness and formed a continuous crack on the inner surface that was shorter than the cracks on the outer surface. The cracks developed near the center of the specimen and propagated in a direction at right angles to the maximum stress. Here again, the large area of approximately the same stress level, as shown by previous illustrations, has resulted in the formation of fatigue cracks over a general area rather than at the geometric center of the specimen.

Most of the fatigue cracks shown were initiated at some point of stress concentration. On one specimen, which had considerable scale and other surface imperfections, the initial crack formed at a very small pit. Another specimen which had a strain-gage test prior to the fatigue test was marked with a number of scribe lines to locate the strain gages. The initiation of the fatigue crack, in this case, was exactly along the scribe line in the longitudinal direction. A typical surface defect which caused a fatigue crack is shown on Fig. 14. This photograph, taken at 30 ×, shows the corner of a sample removed from a specimen. The oxide pit is cut in half to show the fatigue crack propagating along the specimen surface and through the specimen thickness.

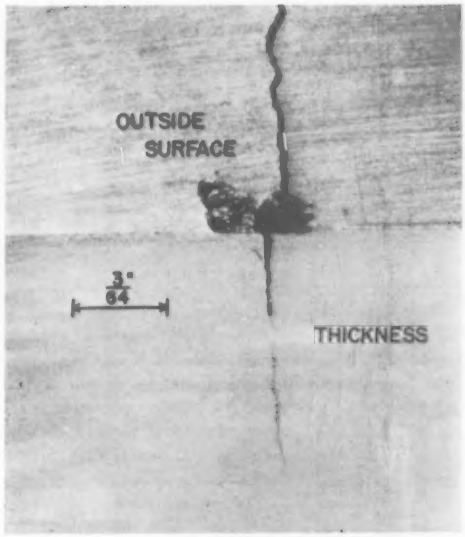


*Fig. 14 View of crack caused by surface defect*

This indication that surface defects, or the near-surface defects, are the cause of failure confirms the conclusions reached in most investigations on fatigue. It should be emphasized that the part of the specimen under observation is the outside surface and a layer of material only a few thousandths of an inch deep immediately below this surface. The specimen, stressed in bending by the hydraulic pressure, has a stress gradient from compression on the inside to tension at the outside. However, in the shallow depth of material under observation, the tension stresses vary an extremely small amount. This effect of the bending is therefore not pertinent. As has been shown, the stresses change very slightly in the two surface directions for a considerable distance from the center of the specimen. This central area can therefore be used to simulate the stress system in a pressure vessel.

## CONCLUSIONS

1. A testing technique has been developed for the fatigue testing of flat-plate specimens under biaxial stress conditions.

2. The testing of flat-plate specimens has an economic advantage over testing full-size or even model pressure vessels.

3. A flat-plate specimen is versatile in the many pressure-vessel design variables that can be tested.

4. Considerable data can be obtained in a short period of time.

5. The testing technique permits the detection of the initial failure as well as the continuation to complete failure of the plate, if desired.

## REMARKS

It is believed that the testing technique described and the data which will be obtained using this technique will be of help in determining some of the basic relations between the physical properties of the various materials and the service conditions under which the materials are used. The relation of fatigue strength under biaxial conditions as compared with fatigue properties using uniaxial stresses on simple specimens should be determined. When the effect of certain of the variables under investigation is determined, the next logical step will be to use model pressure vessels for a few tests to verify the conclusions obtained with flat-plate specimens. The last step would include several full-size test vessels provided with the various necessary features such as manway openings, nozzle connections, etc. When such a program is completed with the cooperation of various industry-wide agencies, we will be much farther along toward our goal of a well-balanced pressure vessel with all components designed to give low stress-concentration factors and with the materials best suited to the expected service conditions.

## ACKNOWLEDGMENTS

The authors wish to acknowledge the detail design work done by M. Solcer and the test work performed by D. E. Price and A. H. Scott. Appreciation is expressed to P. R. Cassidy for his interest in correlating this work with the program of the Pressure Vessel Research Committee.

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# WELDING RESEARCH COUNCIL BULLETINS

The Welding Research Council has inaugurated a series of Bulletins to include reports for which space cannot be provided in the regular Welding Research Supplement. These Bulletins are furnished to the contributors and research workers of the Council and placed on sale at a nominal charge through the American Welding Society. A list of the Bulletins published to date and their prices are:

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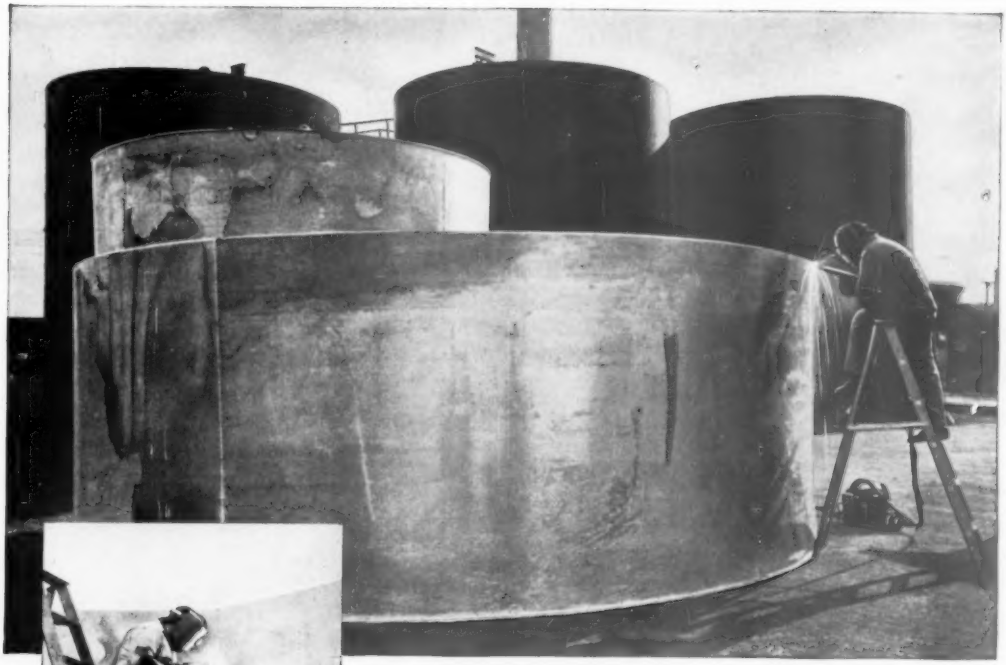

One welder. One helper. The Aircomatic Welding Process . . . and Universal Copper Works, Inc. Newark, N. J. fabricates a 50,000 gallon aluminum industrial acid tank for A. Gross & Company at a savings of 75% in filler rod and 50% in time over previous methods used.

# AIRCOMATIC® WELDING *cuts costs of* "Hungry Acid" Tanks

Experts long knew aluminum was the answer for 'hungry acid' storage tanks . . . acetic, fatty acids, for example. Only a few years ago fabrication of these ideal tanks was a sizable problem.

Today that's all changed. Air Reduction's Aircomatic Welding Process has so simplified tank-building operations, that in-the-field construction has become routine practice.

Based on continuous feeding of bare filler wire in conjunction with inert shielding gases, the Aircomatic Process now presents the welder with these fabrication advantages:

1. Continuous, high-rate deposition of filler metal
2. Semi-automatic, all-position welding
3. Minimum plate-edge preparation
4. Heavy section welding with little or no preheat
5. No flux — elimination of slag removal
6. Visible arc — no blind welding

Find out how you can use Aircomatic welding. Write or phone your nearest Airco office. Ask for your copy of Catalog 17 "The Aircomatic Process". Also, inquire about Airco's film "The Tool for the Job" — the story of Aircomatic in full color.

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